RESEARCH ON WELDING RECONDITIONING OF THE FRICTION LINER FROM PASSENGER CARS FOR RAILWAY SAFETY IMPROVEMENT

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The paper presents the experimental results obtained after conducting research aimed to identify technologies suitable for reconditioning by welding the friction liner on the disc brake from passenger cars. The friction liner is part of the disc brake braking system of passenger cars and is a risk category A part, very important for railway safety. Its failure has two possible effects: the braked running of the train, which results in wheel wear that can repel the wheel, and / or sparks, which can ignite the car, or the impossibility of braking which can lead to serious accidents with possible victims and material damage. The research allowed quantitative and qualitative comparisons of the effects that the various processes / technologies of reconditioning by welding have on some defining elements of a deposit such as: penetration, width, structure, extension of the thermo-mechanically influenced area (HAZ), hardness, etc. The results of the experiments and analysis presented in the article lead to the conclusion that the mechanized welding reconditioning process is the most suitable for the best quality of the reconditioning.

Keywords: welding reconditioning technologies, HAZ, friction liner

1. Introduction

Rail transport is considered an economical, efficient, environmentally friendly and very safe mode of transport. [1] To make it competitive with the other areas of transport is important to keep a good quality at low costs. A low cost solution is to obtain the increase of the lifespan of some components where the acquisition costs are high or for which there are no more manufacturers. Friction

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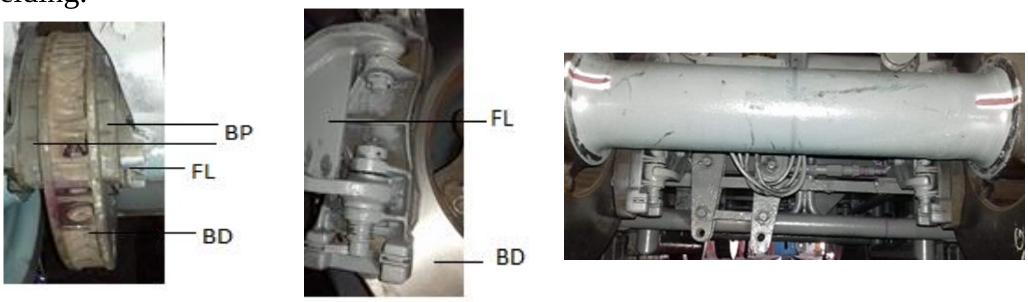
products are safety-critical items that must be carefully designed and selected to ensure that they meet a range of performance criteria [2,3]. The nature and applicability of reconditioning operations largely depend on the type of component to be reconditioned, the manufacturing material, but also the working conditions of the product, i.e. the operating environment.

Optimization of a reconditioning technology must take into account both technological and economic aspects [4]. The friction liner is a very important component for the safety of the vehicle, being included in the category of parts of group A, according to OMT 290/2000 (National regulation), annex 3, chapter II, art. 9, art. a) [5].

Any small failure of this part significantly affects the railway safety. For this reason, the reconditioning technology of a component must lead to the safe use of the entire assembly. The friction liner (Fig. 1) is the main component of the braking system for passenger cars.The present work analyse the reconditioning by welding.



a) b) c)

Fig 1. Example of disc brakes (FL-friction liner, BD brake disc, BP-brake pad) [3]
a) Frontal view; b) Lateral view; c) General view

The most frequent failure of the friction liner consists in the wear of the contact surfaces, due to the forces acting in operation and which leads to the wear of the swallow tail profile, resulting in the loss of the ability to secure the braking pad. The clamping profile between the friction liner and the brake pad is illustrated in Figure 2.

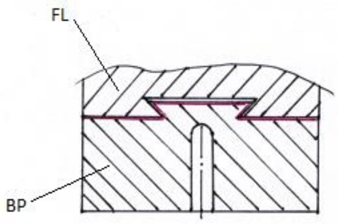


Fig. 2. BP-FL assembly, „swallow tail" catch (FL-friction liner, BP-brake pad) [3]

Reconditioning technologies applied mainly to parts such as friction liner fall into the category of reconditioning technologies by fusion welding.

Taking into account the nature of the base material from which the friction liner is made (cast-iron), the main fusion welding processes suitable to be applied for reconditioning are: manual metal arc welding (MMA); Flux-cored arc welding with active gas shield (FCAW welding); this welding process are identified according to "*ISO 4063: 2009. Welding and allied processes - Nomenclature of processes and reference numbers* as follows" with: 111 manual metal arc welding (MMA), 136 Flux-cored arc welding with active gas shield (FCAW) [6].

The aim is to optimize welding parameters to obtain a higher qualitative weld.

2. Experimental Procedure

The technology of reconditioning the friction gasket involves the following main steps: identification of used areas, evaluation and measurement of wear in order to determine the possibility of reconditioning, mechanical processing of the used area, examination of the processed area, deposition of addition material by welding up to dimensions imposed, examination of the loaded area, subsequent mechanical processing to the profile and nominal dimensions, followed by a final examination. In order to design and apply an adequate technology that would lead to obtaining a deposit of a very good quality and optimal characteristics for the purpose of using the friction liner, sets of experiments with 3 different welding technologies were performed, and samples, subsequently subjected to specific examinations, were processed.

2.1 Materials

2.1.1 Base material

According to the technical specification of the designer, the base material used to make the friction liner is a cast iron nodular graphite type: EN-GJS-400-15C according to EN 1563, GGG40 according to DIN 1693, 0.7040 according to WERKSTOFFNUMMER, and 60/40/52 according to ASTM A536-584. The EN-GJS-400-15C base material, having the chemical composition presented in Table 1, must comply with the indications in the standard "EN1563 Founding - Spheroidal graphite cast irons". Some mechanical characteristics of the base material are presented in Table 2. The standard EN 1563 provides additional information on the values of the characteristics of cast iron type EN-GJS-400-15C: Brinell hardness: 135 - 180HB; Ferrite content: minimum 85%; Impact energy at 20 °C: 10 [J].

Table 1

The chemical composition of cast iron EN-GJS-400-15C [7,8,9]

Chemical Element		C	Si	Mn	S	P	Fe
Standardized value (%)	Min.	3,4	0,1	2,3	-	-	Balance
	Max	3,85	0,3	3,1	0,02	0,10	Ballance

Table 2

Mechanical characteristics of cast iron EN-GJS-400-15C [7]

Base material	Thickness (mm)	R_m min.* (N/mm^2)	$R_{p0.2}$ min.** (N/mm^2)	A min. *** (%)
EN-JS1072	t<30	400	250	15

* Ultimate Tensile Strength; ** Yield Strength; *** Elongation

2.1.2 Filler material

For performing the reconditioning of wear zones of friction liner, two welding processes have been used, MMA (111) and FCAW(136). In order to establish the influence of the welder skill on the quality of the reconditioned part, the FCAW process was applied in two variants, semi-mechanized (coded FCAW) and mechanized (coded FCAWm). The filler metal used in the FCAW and FCAWm processes was chosen taking into account the chemical composition, but also the high plasticity characteristics, in order to dissipate and attenuate the peaks of transient and residual stresses, in order to minimize the deformations of the welded part. The chemical compositions of the filler materials used for experiments are presented in Table 3 and their mechanical properties in Table 4. The filler materials used in the experimental program were:

- Coated electrode for MMA –ENiFeC1 A (according to AWS 5.15, SR EN ISO 1071/2004)
- Tubular wire for FCAW and FCAWm – NiFe 60/40 (according to DIN EN 14700, NiFeCl)

Table 3

Chemical composition of filler materials, wt%

Chemical element	MMA	FCAW and FCAWm
C	1.10	Max 0.5
Si	1.20	Max. 1.0
Mn	1.10	Max 4.0
Ni	54	60
Fe	43	Max 40
Cu	0.6	-

Table 4

Mechanical characteristics of the filler material

<table>
<tr><th rowspan="2">Characteristics</th><th colspan="2">MMA</th><th colspan="2">FCAW and FCAWm</th></tr>
<tr><th>Min.</th><th>Max.</th><th>Min.</th><th>Max.</th></tr>
<tr><td>Ultimate Tensile Strength, R_m (N/mm^2)</td><td>430</td><td>470</td><td colspan="2" rowspan="3">The wire manufacturer does not specify these characteristics [7]</td></tr>
<tr><td>Yield strength, $R_{p0.2}$ (N/mm^2)</td><td>320</td><td>360</td></tr>
<tr><td>Elongation, A (%)</td><td>10</td><td>-</td></tr>
<tr><td>Hardness, HB</td><td>160</td><td>200</td><td>140</td><td>160</td></tr>
</table>

2.2. Equipment and devices used

The equipment and devices used in the experiments are indicated in Table 5. During welding, the device was positioned at different angle according the welding process: 90^0 for MMA and 45^0 for FCAW and FCAWm. The decision to set the positioning angle was made after initial experiments, when liquid metal leaks were found during MMA deposition.

Table 5

Equipment and devices used

No.	Equipment/	MMA	FCAW	FCAWm
1	Welding source	Welding Inverter	Aristo MIG U5000iw	
	Displacement device	-	-	Miggytrac
2	Fastening device positioning *	90^0	45^0	

* inclination related to the horizontal plane;

2.3. Techniques used and welding parameters

The reconditioning of the brake liner was performed in three stages: first stage was the mechanical processing of parts (for ware removal), second stage was the loading with welding beads on both sides of the profile and third stage was the mechanical processing of the part at nominal dimensions.

To reduce the level of internal stresses and to avoid the risk of imperfections formed during and after the reconditioning process, the temperature between the layers (checked by a non-contact pyrometer) must not exceed 200ºC [10].

Each manufacturer of filler materials used in reconditioning technologies by welding cast iron parts makes recommendations regarding the use of that material, concerning welding regime parameters: current, voltage, welding position in which the welding material can be used, filler material, type of current, conditions of use and preparation.

Based on these recommendations, the parameters have been set and recorded during the experiments (values indicated in Table 6). The values of the working process parameters were established so as to obtain equal heat input for the three variants of welding processes, the differences registered for this parameter being only of 0.006 [kJ/mm], with negligible effects. The welded layers were deposited with filiform rows, from left to right, along the entire length.

Table 6

Parameters used in the experienced welding processes

Process	Layer	Ø (mm)	k (-)	U_a (V)	I_s (A)	v_s (mm/min)	E_l (kJ/mm)
MMA 3 layers	Layer 1	2.5	0.8	19	100	140	0.651
	Layer 2	3.25	0.8	21	115	180	0.644
	Layer 3	3.25	0.8	21	120	220	0.550
Average heat input MMA							**0.615**

FCAW * 3 layers	Layer 1	1.6	0.8	21.7	204	350	0.607
	Layer 2	1.6	0.8	22	201	345	0.615
	Layer 3	1.6	0.8	21.5	206	345	0.616
Average heat input FCAW							**0.613**
FCAWm ** 3 layers	Layer 1	1.6	0.8	26	150	305	0.614
	Layer 2	1.6	0.8	27	146	305	0.620
	Layer 3	1.6	0.8	26	152	305	0.622
Average heat input FCAWm							**0.619**

* average values for welding speed v_s, I_s and U_a
** welding speed given by the welding tractor

In the case of MMA process, the weld layer length was obtained by melting two electrodes. After cooling of each layer, the slag was mechanical removed to prevent the appearance of imperfections such as slag inclusions. According to the repair procedure, the successive layers were deposited until obtaining a deposition final dimension of 13 mm width and 9 mm height, which have been performed by 3 successive passes for each sample. Then, the nominal dimensions were adjusted by mechanical processing by milling.

Results and Discussion

3.1. Research stages

In order to obtain the experimental samples, both generally valid steps for all procedures were followed, as well as a series of stages depending on the nature of the reconditioning procedure used. The experimental program designed for reconditioning by welding of the components presented in Fig. 3 comprised the following stages, as follows.

A) *Non-destructive examination*

Each friction liner subjected to the reconditioning process by welding was examined by non-destructive methods: Visual NDT (VT) and Liquid Penetrant NDT (PT). The purpose of this step was to determine whether the degree of wear requires reconditioning (Figure 4).

a)

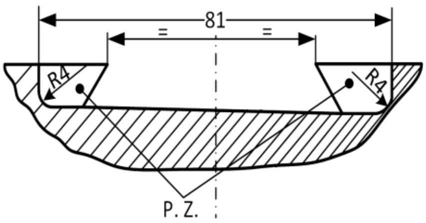
a)

b)
Fig. 3. Components subjected to reconditioning operation by welding
a) top view; b) bottom view

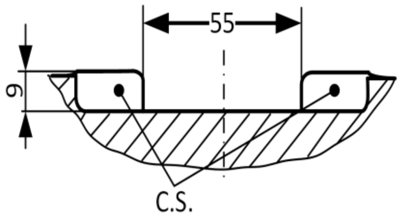
b)
Fig. 4 Visual testing and measurement of worn zones for reconditioning
a) Worn part that needs reconditioning;
b) Part that does not require reconditioning

B) *Preparation of the surface to be reconditioned by welding*

This stage is necessary to remove a layer of wear material in order to restore the operating geometry. This step involves mechanical machining of the dovetail-shaped fixing channel at a 90° angle. The shape and dimensions of the areas processed by milling as well as the areas that will be restored by welding are indicated in figure 5.a and 5.b.



a)



b)

Fig. 5. Shapes and dimensions of processing zones [3]
a) dovetail-shaped zones to be processed by milling (P.Z. – the zone to be removed);
b) zones that will be restored by welding (C.S. – weld deposit)

C) *Welding process*

In welding specification is indicated the dimension and geometry of layers deposited so as to obtain the required width and height of the weld. They must take into account the fact that part of the deposited metal will be removed by subsequent mechanical processing, in order to achieve the desired profile of the part reconditioned by welding.

A specific problem of welded cast iron parts is the occurrence of residual deformations, which can be avoided, in some cases, by using a clamping and fixing device.

The welding deformation is the most important factor that influences the quality of the welding. Welding residual stresses have a negative or positive effect on the strength of the component depending on their type, amplitude, direction and distribution [11]. In order to establish the necessity of the use of the clamping and fixing device, presented in Fig. 6, a series of experiments were performed, which are not the subject of this paper. The previous study consisted in reconditioning using MMA process of piece without the device in comparison with the piece fixed in device, then the deformations against the horizontal plane were measured.

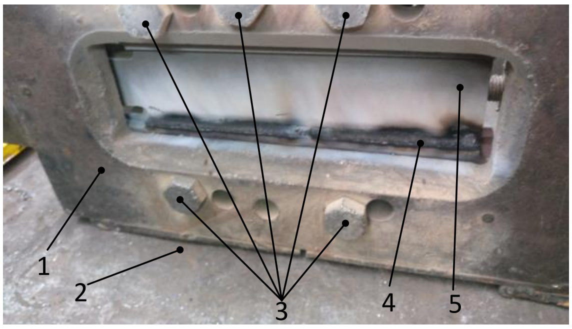


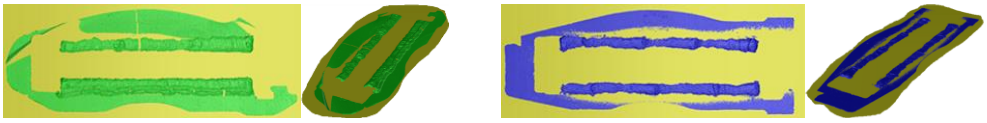
Fig. 6. Welded piece fixed in the device [2]
1 – clamping plate; 2 – working table; 3 - fastening system; 4 - welds; 5 - friction liner body

The 3D scanning images of the obtained samples, presented in figure 7, can highlight the location and amplitude of the deformations appeared in relation to the level of the flat surfaces of the welded parts, as follows:

- 0.58 mm for the piece welded in the fixing device, value accepted according SR EN 22768-1 / 2.

- 3.02 mm for the free welded part, value that exceeds the limits imposed by SR EN 22768-1 / 2.

In view of the above results, the use of a welding device was required.



a) b)

Fig. 7. 3D scanning images highlighting the deformations level
a) Freely welded sample - the yellow colour represents the horizontal plane and the green colour the freely welded piece; b) Sample welded in the device - the yellow colour represents the horizontal plane and the purple colour the piece welded in the device

After each weld layer, the slag was removed, and the inter-layers temperature was measured to not overpass 200^0C.

C) Non-destructive examination after welding

After welding, the cooled pieces were examined using Penetrant Liquid NDT (PT) on the entire length of the weld.

D) *Mechanical processing*
The processing of the welds was performed by milling using a shaped mill. After finishing this stage, the resulting parts were visual examined and the functional dimensions were measured, then new PT examination has been carried out.

3.2. Assessement of the quality level of welding technologies

3.2.1. Welded components

The welding procedures influence the geometry of the joint, the nature and extent of the structural transformations, the level of stresses and deformations and the value of resulted mechanical characteristics (hardness, wear, impact resistance) [12-13]. The welding specifications associated to the reconditioning technology were applied for the realization of the welded samples presented in Fig. 8. According to the images shown in Fig. 8, it can be stated that: in the case of MMA process the welds have a larger width, irregular edges, high number of spatter on the surface; in the case of FCAW process the material loss by spatter is insignificant but are obtained the same irregular edges; using the FCAWm process has been obtained a piece with correct shape of weld.

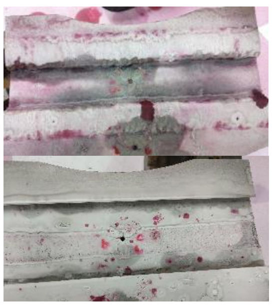
3.2.2. Testing methods

Non-destructive testing methods must be applied both before reconditioning (to decide whether or not the part can be reconditioned), after welding (to check the integrity of the weld and to obtain the correct values of the dimensions and shapes of the processed areas), after mechanical processing at nominal dimensions (for verifying the fulfilment of the requirements regarding the conformity of functional shapes and dimensions, or for identifying possible internal imperfections) [14-17].

After visual and dimensional (OV-D) analysis, the weld components were examined using Liquid Penetrant NDT (PT), the tested zones being shown in Fig. 9.


a)


b)



c)

Fig. 8. Friction lining reconditioned by welding using:
a) MMA; b) FCAW; c) FCAWm

Fig. 9. Different aspects of PT examination and calibration test

The consumables and conditions for performing PT was: FLUXO S 190 type degreaser, FLUXO P125 type penetrating liquid, FLUXO R 175 type developer, sample temperatures 25^{0}C, penetration time 15 min, developer action time: 20 min. The imperfections identified following the OV and PT examination are indicated in Table 7.

Table 7

Identified imperfections

Examination method	Welding Process	Imperfection					
		Surface por	Crater, crack	Lack of fusion	End crater pipe	Crack	Continuous undercut
OV	MMA	X	-	X	X	-	X
	FCAW	X	-	X	-	-	-
	FCAWm	X	-	-	-	-	-
PT	MMA	X	X	X	X	X	X
	FCAW	X	-	X	X	-	-
	FCAWm	X	-	-	X	-	-

X: identified by the examination method; -: not identified by the examination method

3.2.3 Macroscopic analysis

Macroscopic analysis is a method of examination that can be performed with the naked eye, using a magnifying glass (5x magnification), or with other optical devices that allow magnification of up to 50 times. For the microstructural analysis, samples were taken from the welded areas, using mechanical cutting methods, and then the sectioned cross sections were subjected to the metallographic preparation procedure.

The surfaces were first sanded with abrasive paper having different granulations, after which they were polished with abrasive powders until obtaining the necessary quality. To highlight the micro-structural characteristics, the surfaces were etched with chemical reagents suitable for the base material.

The macroscopic images of the cross sections and the imperfections identified in every sample are shown in figures 10 to 13.

The main types of imperfections are: pores (Fig. 10a and Fig.12c) lack of fusion and adherence with base material (Fig. 10c and Fig.12a).

3.2.4. Hardness measurement

Microhardness (HV 0.2) was measured both in weld and in heat affected zone for all the samples obtained with different welding processes: MMA, FCAW and FCAWm.

Hardness tests were performed using Shimadzu HMV 2T apparatus in Lamet Laboratory from University Politehnica of Bucharest. The microhardness Vickers HV0.2 was measured on the polished surfaces of the samples, by setting the parameters as follows: testing time of 10 seconds, pressing force of 0.2N.

According to the applicable standards regarding the establishment of hardness values, the determination is made by measuring in 5 distinct points, in each areas of the joint: base material (BM), heat affected zone (HAZ) and weld (C), Fig. 11.

a) b) c)

Fig. 10. Macroscopic samples
a) Sample MMA; b) Sample FCAW; c) Sample FCAWm

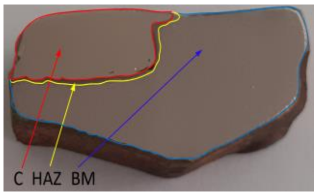


Fig. 11. Identification of zones C, HAZ si BM

Some images of the samples (A, B, C), cut from other areas of reconditioned parts using MMA process, are indicated in Fig. 12.

a) b) c)

Fig. 12. Sample A, B, C identification, taken at MMA welding
a) sample A- manual welding test with device clamp; b) sample B- manual welding test using clamping device and subsequent mechanical processing; c) sample C – free manual welding test without fixing in the device

The microhardness values are indicated in Table 8 for MMA process and in Table 9, for FCAW and for FCAWm processes.

Table 8

Hardness Values (HV 0.2) - MMA process (Fig. 12)

Sample	A		B		C	
	Measuring zone		Measuring zone		Measuring zone	
Measuring point	HAZ	C	HAZ	C	HAZ	C
Point 1	220	183	256	194	286	153
Point 2	228	174	422	195	250	159
Point 3	282	180	418	203	226	167
Point 4	292	176	328	208	373	171
Point 5	210	170	358	225	356	154
Average value	246.4	176.6	356.4	205	298.2	160.8

Table 9

Hardness values (HV0.2) - welded sample FCAW and FCAWm (Fig. 11)

Sample	Sample FCAW		Sample FCAWm	
Zone / Point	HAZ*	CS*	HAZ	CS
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
Average value	278,6	192,2	185,2	209,2

From the microhardness values analysis presented in Table 8 and by comparing the values obtained in case of samples A and B, it can be stated that the subsequent mechanical processing led to the increase of the hardness value in HAZ and C, fact for which it was proposed that the processing be performed with cooling.

By comparing the values of the results indicated in tables 8 and 9, it can be seen that the highest value of hardness was obtained by FCAWm process.

3.2.5. Determination of the average chemical composition of the welding bead

During the reconditioning by welding the heat cycle determines changes in the chemical composition caused by the dilution phenomenon and also changes of the mechanical properties in the zones C, HAZ and MB. Heat input is known to be one of the factors that influence all the tree zones during welding process.

The successive layers can have a positive influence on the mechanical properties of the welded joint [12]. Taking into account this fact, tests were performed to determine the chemical composition on samples taken from reconditioned parts by welding. In the following table are indicated the values only for the representative chemical elements Ni, Mn and Si. It is specified that the values indicated in Table 10 are the arithmetic means of 3 measurements for each sample.

The tests for determining the chemical composition were performed with the Olympus Innov-X DPO 2000 PROFESSIONAL with the characteristics indicated in [13], the exposure time of 10 s, and aimed to establish the influence of welding technology on the chemical composition of the seam.

The measurement errors depend on the measured chemical element and the location of the examination, on the exposure time but for the determined determinations they had average values of: ± 0.1 for Ni, ± 0.02 for Mn and ± 0.06 for Si.

Table 10

Chemical composition of samples

Reconditioned by:	MMA*	MMA**	FCAWm	FCAW
Chemical Element	(%)	(%)	(%)	(%)
Ni	46,656	43,74	58,936	55,197
Mn	0,912	0,783	3,086	3,55
Si	1,988	2,52	1,231	1,39

* friction liner positioned in the device and reconditioned by welding
** friction liner reconditioned by welding without using the device

4. Conclusions

From the research realized, a series of conclusions can be drawn, such as:

- Using of a tightening and fixing device, that allow to reduce the deformation level during welding, is necessary in all the case the reconditioning technology is used.
- 3D scan analysis can provide useful information about the deformation mode and shape deviations of the welded samples
- By using the FCAWm process, a good uniformity of the welding surface and the penetration depth was obtained, which qualifies this process as optimal compared to the manual welding process.
- Average values of the hardness reached in HAZ were higher than those measured in CS, for all samples analysed in the paper.
- The chemical composition analyse show the increase of Mn content in the hardfacing zones in both processes FCAW and FCAWm, which contribute to the increasing of the hardness and wear resistance.
- For the implementation of the new reconditioning technology, the researches will be continued in order to determine the values of the wear resistance of the layers deposited by welding, compared to the base material.

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