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PRACTICAL ASPECTS OF PART RECONDITIONING BY WELDING

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Abstract. The restoration of machine functionality through the reconditioning of worn parts is an effective method of reducing repair costs and time, eliminating the need to purchase replacement parts and, in some cases, extending the service life of components. The process includes stages such as cleaning, defect identification, determination of material properties, and the selection of suitable reconditioning methods and materials. Due to its versatility and low cost, welding is used in more than 80% of metal reconditioning cases. The article presents the stages, procedures, and technological parameters of part reconditioning by welding, the criteria for selecting the appropriate processes, and the analysis of possible defects, while also providing recommendations for their prevention.

Keywords: *reconditioning, welding, surfacing, defects, thermal cycle, technological parameters.*

Rezumat. Restabilirea funcționalității mașinilor prin recondiționarea pieselor uzate este o metodă eficientă de reducere a costurilor și duratei de reparație, eliminând necesitatea procurării pieselor de schimb și, în unele cazuri, prelungind durata de funcționare a componentelor. Procesul include etape precum curățarea, identificarea defectelor, determinarea proprietăților materialului, alegerea metodei și a materialelor de recondiționare. Datorită versatilității și costurilor reduse, sudarea este utilizată în peste 80% din cazurile de recondiționare metalică. Articolul prezintă etapele, procedurile și parametrii tehnologici ai recondiționării pieselor prin sudare, criteriile de alegere a procedeelor și analiza defectelor posibile, oferind totodată recomandări pentru prevenirea acestora. Articolul dat tratează detaliat etapele și procedurile recondiționării pieselor prin sudare, regulile alegerii metodelor de sudare, defectele posibile și căile de prevenire a lor.

Cuvinte cheie: *recondiționare, sudare, încărcare, defecte, ciclul termic, parametri tehnologici.*

1. Introduction

The reconditioning of worn industrial parts is an increasingly important solution for extending the service life of equipment and reducing maintenance costs. Statistics show that approximately 85% of machine failures originate from wear of contact surfaces rather than structural damage [1, 2], which highlights the practical relevance of reconditioning technologies.

International experience (Bosch, DelcoRemi, Cardone Industries, TRW) demonstrates that reconditioned parts represent up to 40% of all replacement components in highly industrialized economies [3]. From an economic perspective, reconditioning requires only 10–25% of the cost of a new part and reduces execution time by approximately 45% [4], also decreasing material consumption by nearly 80%. Environmentally, the process significantly reduces metal waste and CO_2 emissions [5]. Despite its advantages, welding-based reconditioning presents challenges related to thermal impact, residual stresses, geometric distortion, and the occurrence of defects such as cracks, porosity, or slag inclusions. These issues mainly arise from incorrect parameter selection, improper surface preparation, or inadequate post-weld treatment.

The aim of this article is to analyze the stages, technological parameters, and procedures used in welding-based part reconditioning, emphasizing the criteria for selecting appropriate processes and the typical defects that may occur. To achieve this aim, the following objectives were established:

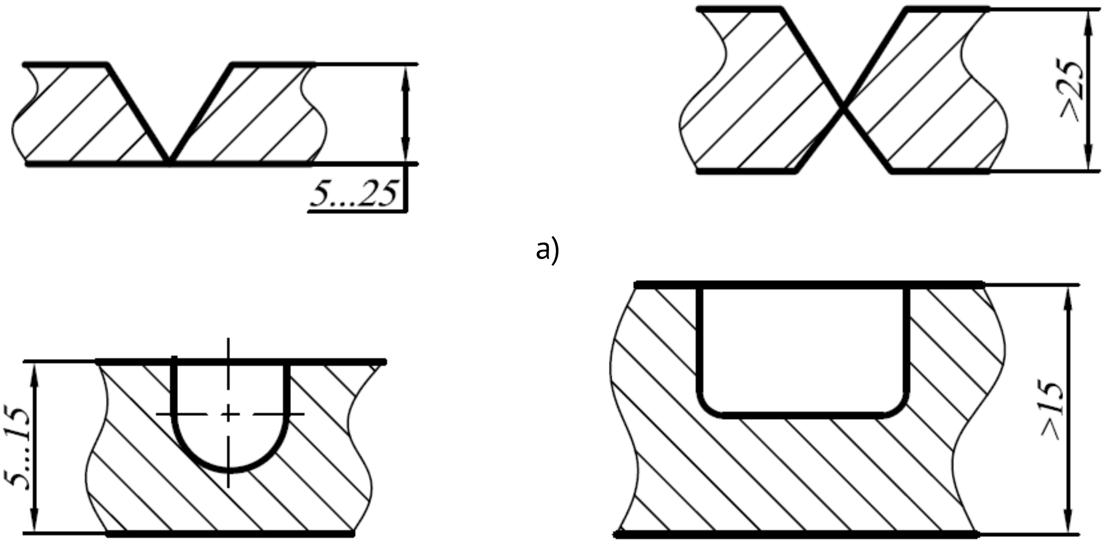
1. To review the stages of part reconditioning by welding and describe the preparation and execution steps.
2. To present the main welding processes applicable to reconditioning and the technological parameters influencing the quality of the deposited layer.
3. To analyze typical defects occurring during reconditioning and identify their causes.
4. To evaluate the influence of thermal cycles and welding parameters on structural integrity and durability.

2. Materials and Methods

2.1. General Stages of Reconditioning

The reconditioning process consists of several well-defined stages [6–9]:

1. Cleaning and inspection– removal of impurities and detection of cracks, voids, or inclusions.
2. Surface preparation– mechanical processing (e.g., chamfering, milling), protection of adjacent areas (Figures 1-3).



a)

b)

Figure 1. Preparation of weld joints for crack removal:
a) for removing single penetrated cracks; b) for removing multiple embedded cracks.

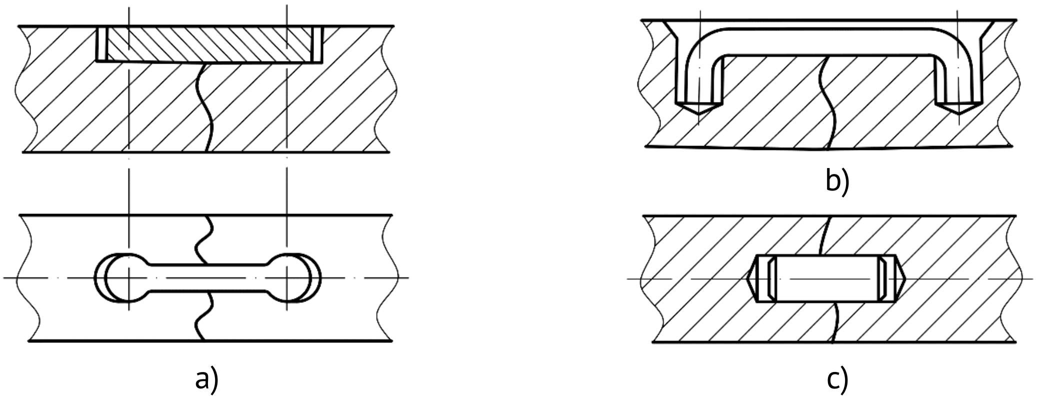

b)
a)
c)

Figure 2. Introduction of additional elements: a) plates; b) clamps; c) pins.

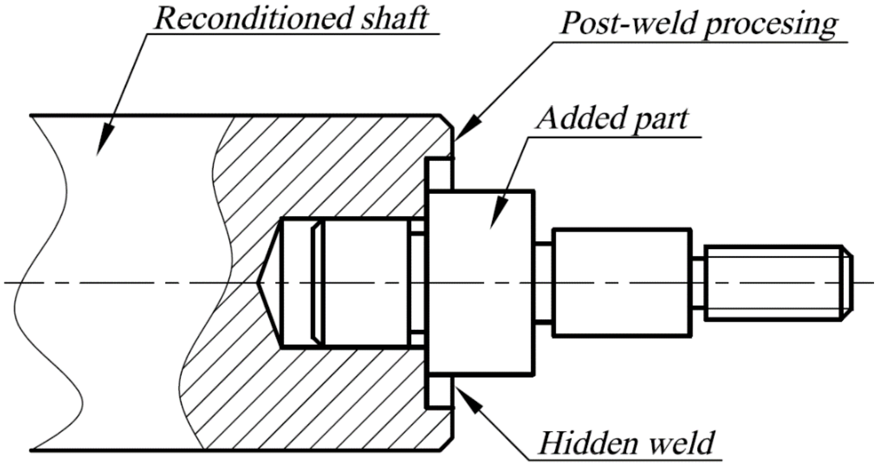
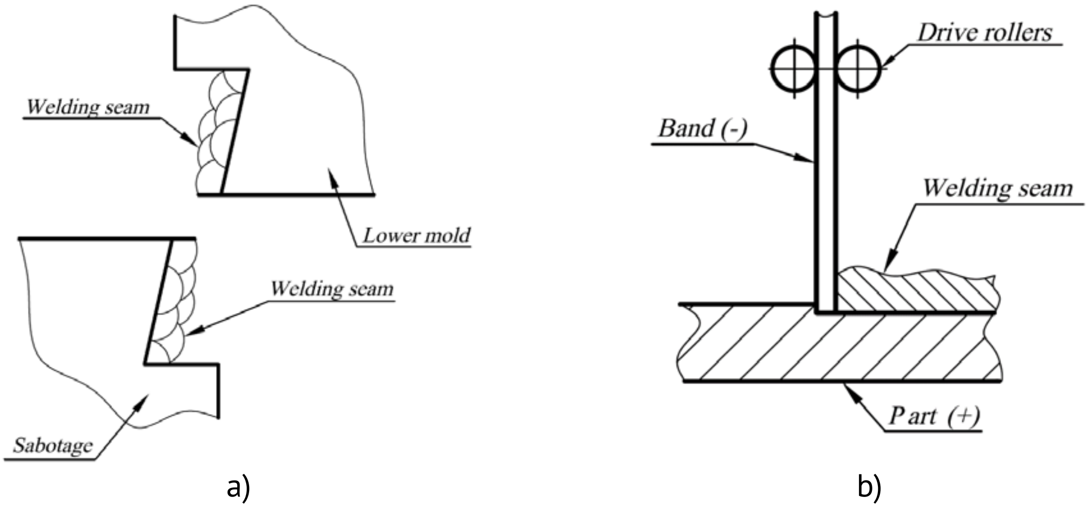


Figure 3. Shaft reconditioning by replacing a broken section.

3. Selection of welding method and filler metal – based on material type and defect characteristics.
4. Welding/Surfacing– gradual deposition of thin layers to minimize internal stresses [10], (Figures 4 and 5).
5. Post-welding treatments– thermal processing to reduce stresses and mechanical machining to restore geometry [11].
6. Final inspection– non-destructive testing of deposited layers.



a)
b)

Figure 4. Surface reconditioning by overlaying: a) with wire; b) with strip.

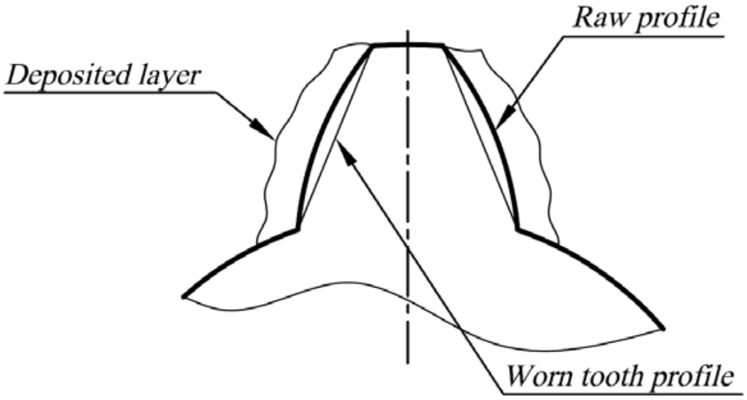


Figure 5. Gear tooth surface reconditioning by mechanical processing.

2.2. Classification of Parts and Functional Requirements

Based on operating conditions, reconditioned parts fall into several categories [12–14]:

- Metal-to-metal friction parts (shafts, gears): require hardness similar to base metal [15,16].
- Abrasive-load parts: require chromium-rich filler materials.
- High-temperature components (dies, rolling mill rolls): require heat-resistant alloys.
- Sliding bearings: copper or cast-iron based filler materials.
- Cutting tools: high-alloy steels.

2.3. Welding Methods Used in Reconditioning

The choice of welding process depends on geometry, thickness, and required mechanical properties [17–21], (Table 1).

Table 1

Welding Methods in Reconditioning

Method	Typical use
Shielded metal arc welding (SMAW)	Simple, economic; thickness > 50 mm
Submerged arc welding (SAW)	Cylindrical parts D > 200 mm
Gas metal arc welding (GMAW)/CO_2	Thin parts (1–4 mm), high productivity
Tungsten inert gas (TIG)	High-quality surfacing, fine structure

2.4. Calculation Formulas and Technological Parameters

When the electric arc is initiated, a molten metal pool forms, and as the electrode moves, it leaves behind a weld bead characterized by its length (L), width (B), height (h), and penetration depth (H) (Figure 6) [17,18].

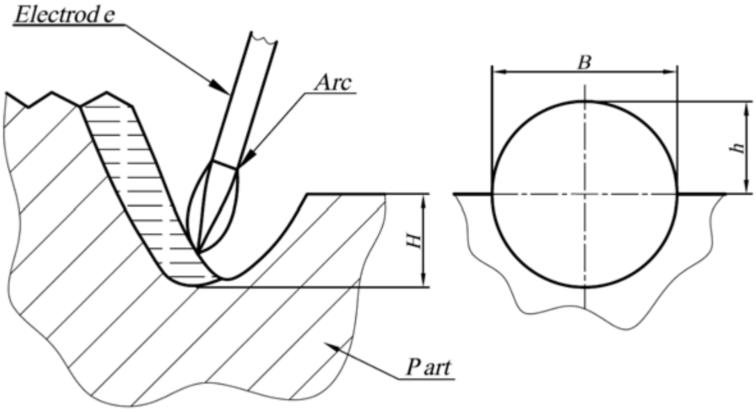


Figure 6. General view of the weld pool.

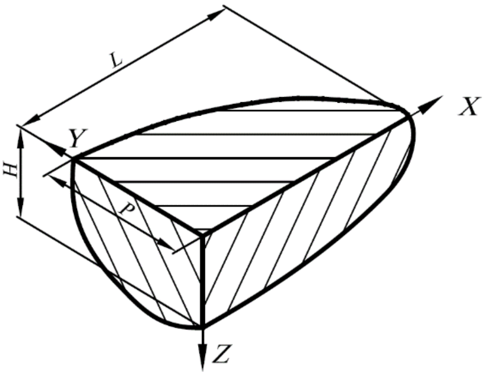


Figure 7. Shape of the weld pool.

For engineering calculations, it is sufficient to approximate the weld pool volume as an ellipsoid with dimensions L (length), P (width), and H (depth), aligned with a coordinate system X, Y, Z (Figure 7).

According to the simplified calculation, the volume of the weld pool is determined using the following relationship:

$$V = L \times P \times H; \tag{1}$$

The length of the weld pool can be determined using the following relationship:

$$L = K\frac{(I \times U)^2}{V_S \times G^2} \tag{2}$$

The depth (which is approximately equal to the height *H*:

$$H = K\frac{I \times U}{V_S \times G}, \tag{3}$$

where: K is the welding parameters coefficient, taking into account the type of current, polarity, and electrode (wire) diameter; I and U are the welding current intensity and voltage; Vs is the welding speed; and G is the thickness of the welded material.

Depending on the welding voltage, and welding wire diameter 1,2 mm, the welding current value can be selected from the nomogram shown in Figure 8. The current is adjusted more precisely after the test passes are made.

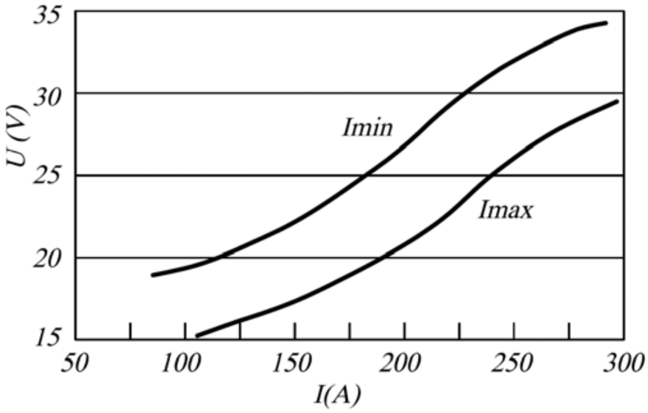


Figure 8. Welding current nomogram as a function of voltage for a wire with a diameter of 1.2 mm.

The mass of molten metal per unit of time effectively represents the welding productivity. Increasing the welding current and the wire feed speed leads to an increase in this productivity (Figure 9).

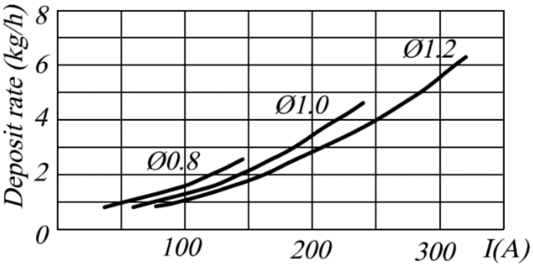


Figure 9. Deposition rate as a function of welding current and wire diameter.

2.5. Thermal Analysis of the Welding Process

As already mentioned, the thermal influence on the parts can lead to changes in the properties of the base material. Therefore, it is important to know the heating speed and temperature of the reconditioned layer of the part, as well as the cooling time until the initial temperature is reached.

The thermal cycle during welding can be characterized by the graph shown below (Figure 10).

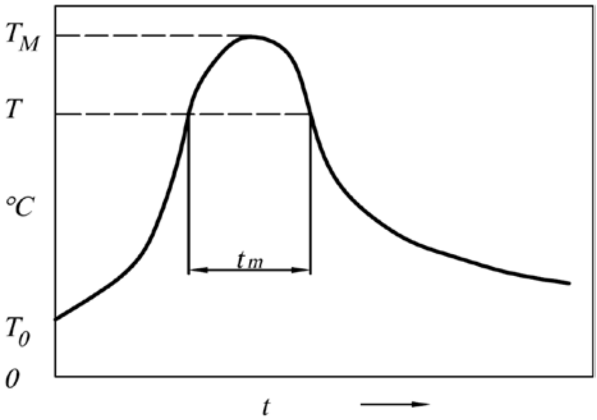


Figure 10. Thermal cycle during welding. T_M is the maximum temperature, T is the holding temperature, T_0 is the initial temperature (500-600 °C), and t_m is the time for holding the initial temperature.

In the case of electric welding, the cooling rate is determined using the following relation:

$$V_R = \lambda \times (T - T_0 \times V_S)/q, \tag{4}$$

where: q is the effective power of the welding source, obtained by subtracting the arc power q_a and the energy lost through conduction and convection q_p:

$$q = q_a - q_p \tag{5}$$

The analytical determination of energy losses is quite difficult, so for practical calculations, a reduction of 8...15% is assumed:

$$q = (0.85 \ldots 0.92) \times \frac{U \times I}{60 \times V_S} \tag{6}$$

The time for holding the initial temperature:

$$t_m = \frac{2K \times q}{V_S \times \lambda \times (T_M - T)}, \tag{7}$$

where: λ is the coefficient that takes into account the volume of the material in the part.

If the holding time is exceeded, welding parameters are modified to avoid potential defects. Defects in the form of slag inclusions can be caused by factors such as excessive humidity, contaminants in the welding area, or incorrect arc length.

3. Results and Discussions

3.1 Influence of Welding Parameters on Bead Geometry

Using the formulas presented in Section 2.4, the influence of current I, voltage U and travel speed V_s on bead geometry was evaluated.

The calculated examples show that:

Increasing welding current from 120A to 160A increases the bead depth H by approximately 18–25%, which confirms the direct proportionality described by formula (3).

A 20% increase in travel speed reduces bead width and penetration by 12–15%, increasing the risk of lack of fusion.

For thin parts (1–4 mm), the recommended parameter interval (Figure 8) corresponds to stable values of L and H, reducing overheating and distortion.

These correlations support the practical rule that stable and moderate heat input ensures uniform bead formation and fewer defects.

3.2 Thermal Cycle Evaluation and Structural Effects

The thermal cycle computed using relations (5) – (7) confirms that:

The cooling rate V_R increases significantly when welding speed is raised.

For example, doubling travel speed increases V_R by about 70%, which may cause excessive hardness in alloy steels.

The effective heat input q varies between 0.42 and 0.55 kJ/mm for the analyzed values of U, I and V_s.

Values above this interval correlate with:

- coarsened microstructure,
- increased deformation,
- formation of tension zones promoting cracking.

Holding time t_m in the critical temperature range (600–800 °C) decreases with higher thermal conductivity λ and higher welding speeds.

These results support the practical necessity of controlling interphases temperature, preheating and bead sequencing for ensuring structural stability.

3.3 Comparative Performance of Welding Methods

Analysis of the main processes (SMAW, SAW, GMAW/CO_2, TIG) using the data in Section 2.3 shows (Table 2):

Table 2

Comparative Performance of Welding Methods

Process	Advantages	Limitations
SMAW	Flexibility, low equipment cost.	Higher slag inclusion probability.
SAW	Ideal for cylindrical parts; deep penetration.	Higher slag inclusion probability.

Continuation Table 2

GMAW/CO_2	Highest productivity; uniform bead; low porosity.	Sensitive to rust/impurities.
TIG	Excellent surface finish; minimal dilution.	Low deposition rate.

Note: SMAW - shielded metal arc welding; SAW - submerged arc welding; GMAW - gas metal arc welding; TIG - tungsten inert gas.

Experimental and industrial data [7, 10, 23, 24] indicate that GMAW and TIG produce reconditioning layers with fewer discontinuities and up to 30% lower residual stresses compared to SMAW.

3.4 Analysis of Defects and their Causes

Correlating industrial observations with parameter calculations, the following trends were identified:

Cracks appear at high cooling rates (low q, high V_s) and insufficient preheating.

Porosity is primarily caused by:

- contamination (oil, rust),
- improper shielding gas conditions for GMAW/TIG.

Slag inclusions occur mainly in SMAW and SAW when bead overlaps are insufficient.

Geometric distortion correlates directly with excessive heat input and irregular bead sequencing.

A properly optimized process—correct I, U, V_s, adequate preheating and post-weld treatment- reduces defect occurrence by up to 40–60%, as indicated by literature and industrial reports.

3.5 Environmental and Economic Considerations

The results confirm that:

Reconditioning reduces CO_2 emissions by over 60% compared to producing new parts.

Material consumption is reduced by approximately 75–80%, especially for large shafts, housings and gears.

For typical industrial components, reconditioning costs represent only 10–25% of the cost of a new part.

Thus, the analyzed technological parameters directly affect economic efficiency, because lower defect rates imply fewer reworks and less material waste.

4. Conclusions

1. The analytical correlations obtained from bead geometry and thermal cycle formulas confirm the decisive role of current, voltage and travel speed in determining penetration depth, bead width and cooling rate. Proper parameter selection reduces defect probability and improves structural integrity.

2. Thermal cycle evaluation demonstrates that excessive heat input leads to microstructural degradation and geometric distortion, while optimal heat input ensures dimensional stability and uniform hardness in the deposited layer.

3. Comparative process analysis shows that GMAW and TIG offer the best quality for reconditioning, producing smooth layers, minimal porosity and lower residual stresses, while SMAW and SAW remain suitable for thick or large cylindrical parts.

4. The main defects—cracks, slag inclusions, porosity and local deformations—are strongly correlated with improper parameter selection, insufficient surface preparation and inadequate preheating. Optimizing these factors reduces defect occurrence by up to 60%.

5. Environmental and economic evaluation confirms the high efficiency of welding-based reconditioning, with material savings of 75–80%, CO_2 reduction above 60%, and total costs representing only 10–25% of manufacturing new parts.

Conflicts of interest: The author declares no conflict of interest.

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