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METHODOLOGY FOR THE DEVELOPMENT OF MINING COMPONENT RECOVERY PROJECTS: A CASE STUDY

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It is widely known that the components of mining equipment are susceptible to wear due to the operation and demands to which they are subjected during their useful life. The deterioration of these is greater or less depending on the working conditions to which they are subjected. There is a critical point, where the piece will be defined as physically unusable, that is, it has lost its permissible working parameters, being unusable for its continued use. Given this situation, two options are proposed: on the one hand, the part can be changed, or on the other, it can be subjected to a technological process that guarantees the return of its capabilities. At the Piloting Centre "Atacama Desert" of the University of Antofagasta (CPDA-UA). The methodology has been elaborate to develop projects that allow the design of processes for the recovery of mining equipment components. The technological system resulting from these projects will be transferred to SMEs in the regional industry. To date, 11 recovery projects associated with 8 different companies have been supported. Through the presentation of a real case study, the developed methodology will be demonstrated.

Keywords: Recovery of components; Engineering projects; Mining equipment; CAD-CAE tools

METODOLOGÍA PARA EL DESARROLLO DE PROYECTOS DE RECUPERACIÓN DE COMPONENTES MINEROS: ESTUDIO DE CASO

Es ampliamente conocido que los componentes de los equipos mineros están sometidos a desgastes debido al funcionamiento y exigencias a las que se ven sometidos durante su vida útil. El deterioro de estos es mayor o menor según las condiciones de trabajo a los que están sometidos. Existe un punto critico, donde la pieza será definida como inservible físicamente, es decir, ha perdido sus parámetros permisibles de trabajo siendo inutilizable para la continuación de su utilización. Dada esta situación, se plantean dos opciones, por un lado, se puede proceder a un cambio de la pieza, o por el otro, se puede someter a un proceso tecnológico que garantice la devolución de sus capacidades. En el Centro de Pilotaje “Desierto de Atacama” de la Universidad de Antofagasta (CPDA-UA). Se ha elaborado una metodología propia para desarrollar proyectos que permita diseñar procesos para la recuperación de componentes de equipos mineros. El sistema tecnológico resultante de estos proyectos será transferido a las pymes de la industria regional. Hasta la fecha se apoya 11 proyectos de recuperación asociados a 8 empresas diferentes. A través de la presentación de un estudio de caso real se demostrará la metodología desarrollada.

Palabras clave: Recuperación de componentes; Proyectos de ingeniería; Equipos mineros; Herramientas CAD-CAE

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1. Introduction

Due to the instability of the price of copper and its fall during times of pandemic, the current situation of mining companies is to increase the availability of their physical assets for those critical components. Instead of being replaced by new ones, these components can be recovered and thus achieve equal or better availability, but at a lower cost – and thus maintain the profitability of physical assets.

Many companies now take back their products to recycle the material in new products. However, there may be a significant economic benefit in remanufacturing/repairing these items instead of recycling them. Circular Economy (CE) has become popular, gaining momentum in China and Europe. CE minimises the consumption of virgin resources and primary energy at a macro-scale, maximising the recycling and recovery of material and energy (Walmsley et al., 2019). Many companies, including Rolls-Royce, MTU, General Electric, Caterpillar, and Cummins Engine, have recognised significant business opportunities in the aftermarket for remanufactured products (Gao et al., 2010).

This reorientation creates an opportunity for regional metal-mechanic companies that, although they make recoveries under exceptional circumstances, become a routine work strategy with random technological performance. This implies that the current recoveries, which are not well-positioned in the clients, are improved to achieve a world-class company performance by recovering parts and pieces with high quality, high reliability, and at reasonable prices in a usual way. In this scenario, a relevant aspect is the size of the parts and pieces of the mining industry, which makes it necessary to have large equipment for handling and the form of application of recovery technologies.

Many factors can affect a piece or metal structure, causing damage or deformation, detrimental to the industry's material properties and the economy. These factors include wear, fatigue, and corrosion. Wear is one of the main factors responsible for most deterioration and out of service of mechanical parts, while corrosion is responsible for the deterioration of metal structures. On the other hand, fatigue only causes damage when the part or mechanical element exceeds the value of the allowable cyclic stresses (Luddey & Trujillo, 2007). During operation, certain parts of the road-construction machinery are exposed to different abrasive materials that cause most of the damage to the parts in direct contact with the stone aggregate, causing abrasive wear. Hard and sharp-edged particles of stone materials are highly abrasive, and they damage the working parts of bucket teeth (Lazi et al., 2015).

Damaged or broken parts are generally too expensive to replace or are no longer available. Reverse Engineering can be defined as the systematic evaluation of a product with the purpose of replication. This involves the design of a new part, a copy of an existing part, recovery of a damaged or broken part, improvement of model precision and inspection of a numerical model. Advantages of the technique include immediate feedback, data reduction, direct generation of geometry and higher precision of the final product. This paper shows some possibilities of use and benefit from utilising the RE-methodologies and techniques in the production process, especially when parts without 3D-CAD support exist. The applications of RE in the industrial area are defined in the following aspects, recovery of a damaged or broken component. If the surface of a part to be measured is damaged or worn away, the reconstructed CAD model may not be precise compared with the proper surface of the part (Bagci, 2009; Li et al., 2017)

In practice, many parts of intricate shapes are subjected to wear due to heavy service conditions and are to be surfaced for rebuilding their nominal shapes and properties. The surfacing process automation of intricate shape parts, necessary in such cases, is possible with industrial robots, and the most suitable surfacing method is GMA welding. The welding robots' high repeatability, productivity and economic efficiency, besides their natural flexibility, are also applicable to the robotic surfacing systems. The robotic GMAW surfacing installation should fulfil the following requirements (Kolasa et al., 2015):

It should assure the possibility of depositing filler metal on the whole outer surface of the work or only on its selected areas,

- The surfacing process should produce the beads of the exact cross-section dimensions depending on electrode wire diameter and welding process parameters
- The surfacing process should assure the restoration of the work parts to their nominal shapes and dimensions within specified tolerances,
- The surfacing process parameters and kind of filler materials have to assure high quality, faultless sur-facing layers with an optimal dilution as well as multilayer deposit welding without the necessity of any interbeat or interlayer operations,
- The entire surfacing installation should be an environmentally friendly system

This paper presents the process of recovery of parts and pieces consisting of the reuse of the main body:

a. Removing the deteriorated material.
b. Identifying the base material.
c. Selecting the appropriate coating material.
d. Applying the necessary coating layer.

Machining the body to achieve the original dimensions allows for the correct functional performance of the component, part or piece.

1.1. CAD/CAE tools

Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE) are two essential tools for designing and developing new products. CAD systems help design a new product efficiently, whereas CAE systems predict and assess a product's future functionalities (durability, structural strength, etc.)(Khan & Rezwana, 2021). CAD tools, therefore, allow the components to be recovered from being modelled, either by having the plans or through 3D scanning of the part. On the other hand, CAE tools allow us to simulate the components' behaviour to understand the observed wear.

These tools, on the other hand, allow us to design the manipulators that will allow the movement of the component and its recovery by welding. (Bilancia et al., 2019; Seth et al., 2022).

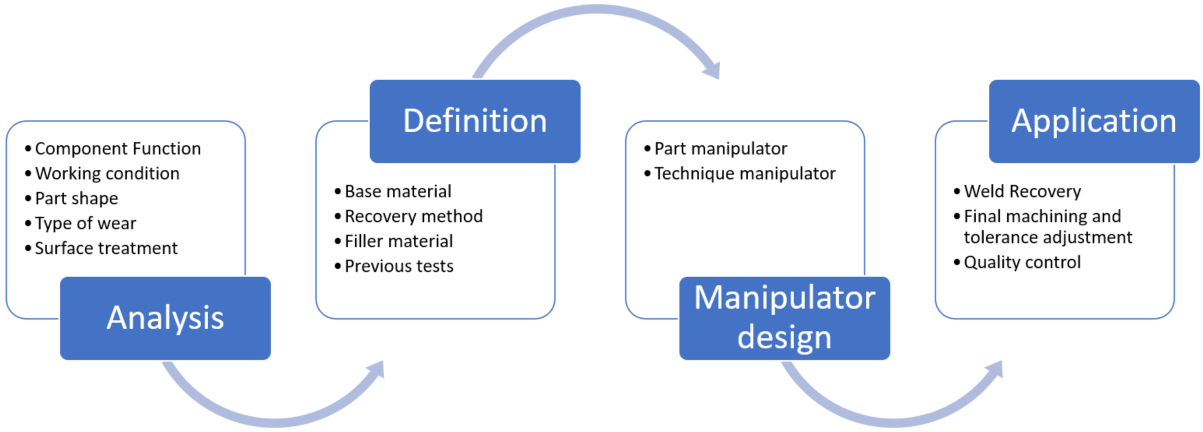
1.2. Objectives

This paper aims to show the methodology for the development of projects for the recovery of mining components, which is created from the project Technological System for the Recovery of Components for the Improvement of Competitiveness and Regional Business Development, which seeks to generate projects for the Recovery of Components in regional metalworking SMEs, for opening new businesses.

2. Methodology

This section details the most critical steps, their explanation, and the mode of operation for recovering parts. In Figure 1, it can be seen the general process.

Figure 1. Methodology recovery components.



2.1. Component Analysis

In this first stage, it is necessary to obtain complete information on the main characteristics and properties of the component. This analysis of the defect allows to correctly define the function of the component, its working condition, the shape or geometry of the part, the type and magnitude of the wear to which it is subjected, and, finally, the surface treatment that is applied to it the part before its operation.

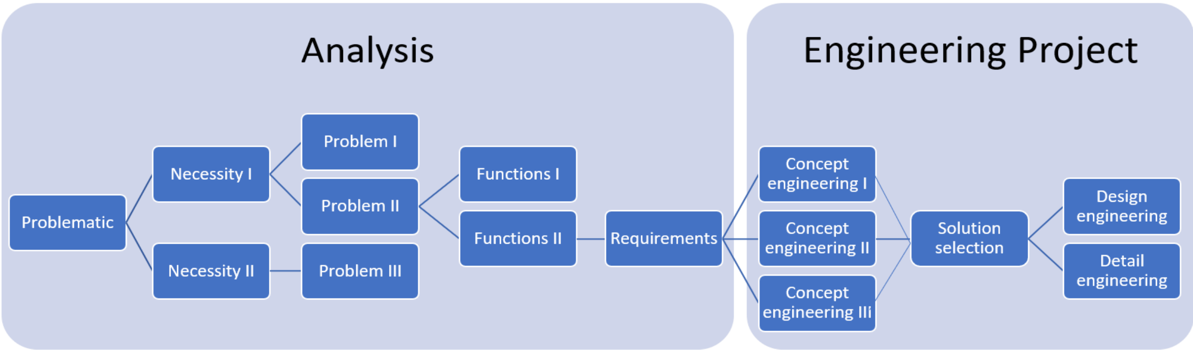
2.2. Definition

In this stage, the base material characteristics are defined via material characterisation, Hardness test, tensile test, fatigue test, metallography, penetrating inks, magnetic particles, and ultrasound. The material base information allows defining the recovery method by welding and the necessary filler material. In addition, the welding method is a significant input variable because this method indicates the trajectory and position of the welding torch.

2.3. Manipulators design

In the design stage of the manipulators, it is necessary to have a well-defined welding technique and the application step by step. The design and development methodology of innovative products developed by the Research Group in Productive Development of the University of Antofagasta is used in the design stage. (Perez-Ubeda et al., 2015). The specific part of the analysis in the design method is very intertwined with the information obtained from the recovery technique. That is, part of the requirements is known. However, it is also essential to consider the opinion of the stakeholders. As shown in Figure 2, the global problem must be clearly defined, the specific needs that arise from the problem, the problems associated with each need, and the functions and restrictions with their corresponding variable (requirement). This analysis process tells us how the welding process will be; therefore, it will allow us to define how the welding torch has to be moved (technical manipulator) and the piece to be recovered has to be moved (manipulator of the technique). Component). After the development of several alternatives and their technical-economic evaluation determined in the conceptual engineering, the most appropriate solution is selected, and the development of the design engineering and detailed engineering continues.

Figure 2. Methodology of Manipulators design



The output of this stage will be the manufacturing plans of the technique and piece manipulators.

2.4. Application

In the last stage of the application of the recovery process, the previously designed manipulator(s) are available. Therefore, this stage considers the actual operation of the recovery process, which implies the construction of the manipulators and the application of the recovery. In this way, the corresponding quality analyses are carried out.

3. Results: Case Study

3.1. Context

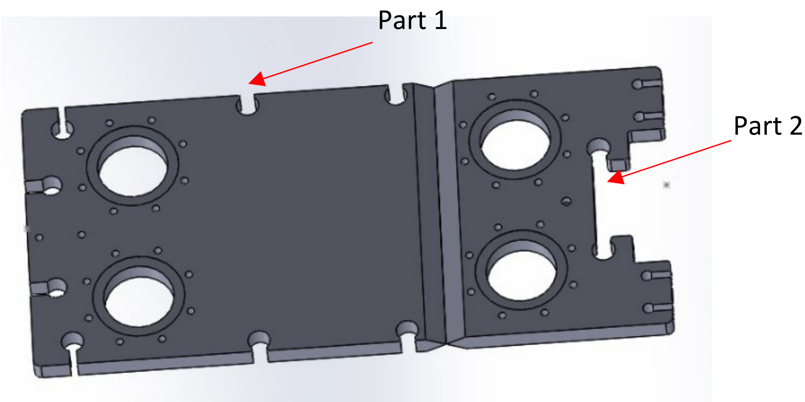
This case study uses the project of recovery of the company "Termia" with the component "Heat Exchanger Plate". Termia presents the problem of its heat exchanger plates, as shown in Figure 3. These plates are damaged in the lower part due to chemical corrosion of the liquid that circulates through its ducts, presenting material detachment, as mentioned in the technical report of Radiadores Gómez. Currently, the company sends to manufacture or compare the new plate with a high cost. With the project, recovery of existing plates will be carried out, lowering costs and repair times.

Figure 3. Heat Exchanger Plate

3.2. Recovery technique

Termia company provides the plans and measurements of the heat exchanger plate. The 3D design with this information is shown in Figure 4. Before welding, the process consists of cutting the worn part b and replacing it with a new one of the exact dimensions. Therefore, it is where the pieces are joined through the edge generated by the bezel.
Before welding, the process consists of cutting the worn part b and replacing it with a new one of the exact dimensions. Therefore, it is where the pieces are joined through the edge generated by the bezels.
In the report on the recovery technique, the need arises for a manipulator to achieve the recovery of the plate. This must be welded in sections and on both sides, exchanging welding steps according to the procedure. A handling system can rotate the plate to apply lap welding to achieve recovery while the plate remains horizontal.
The manipulator must support the heat exchanger plate and, at the same time, allow it to rotate to weld face A and then face B according to the steps indicated in the recovery technique.

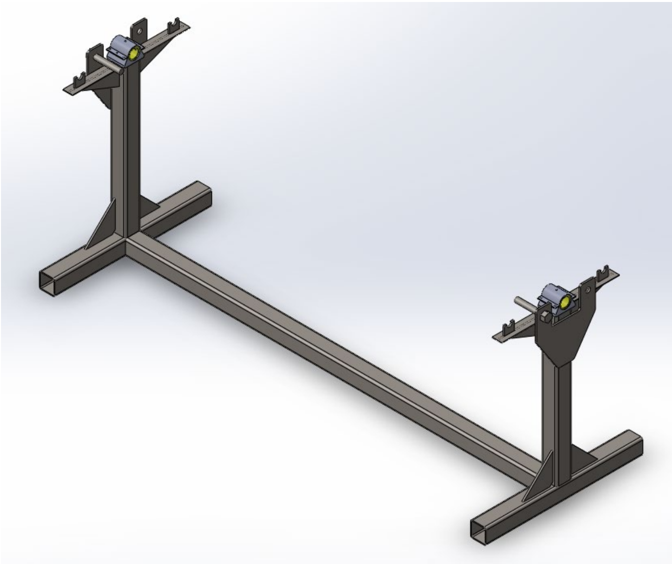
Figure 4. Heat exchanger plate.



3.3. Manipulator design

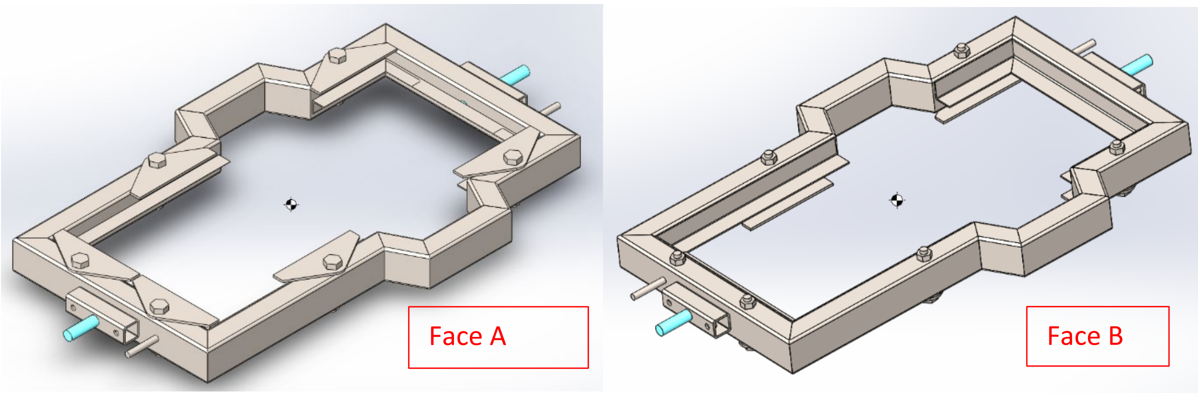
The support system refers to the structural base that will support the Heat Exchanger Plate; the support design is based on square profiles capable of supporting the weight of the plate and its rotation, as shown in Figure 5. In the case of the piece manipulator, after several iterations, the design of a structural bench was arrived at, plus a structural frame where the piece is supported. This bench allows the piece to be rotated 180° to weld one side or the other while waiting for the cooling times.

Figure 5. Structural support bench.



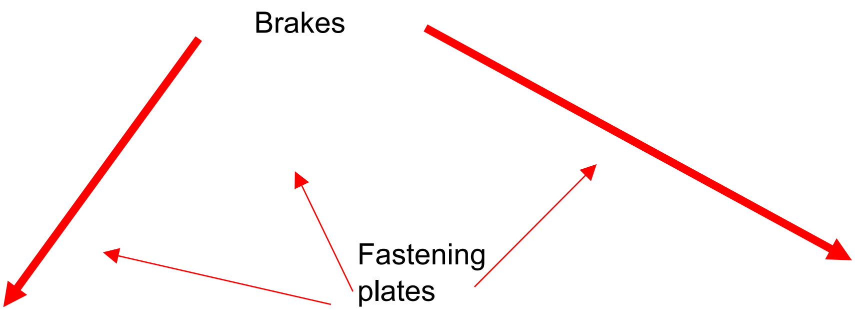
In order to join the two sections of the plate, a table is designed to support the plate and perform alignment and join both parts of the plate for the application of welding. The design can be seen in Figure 6. Face A has the fastening plates upwards, Face B downwards.

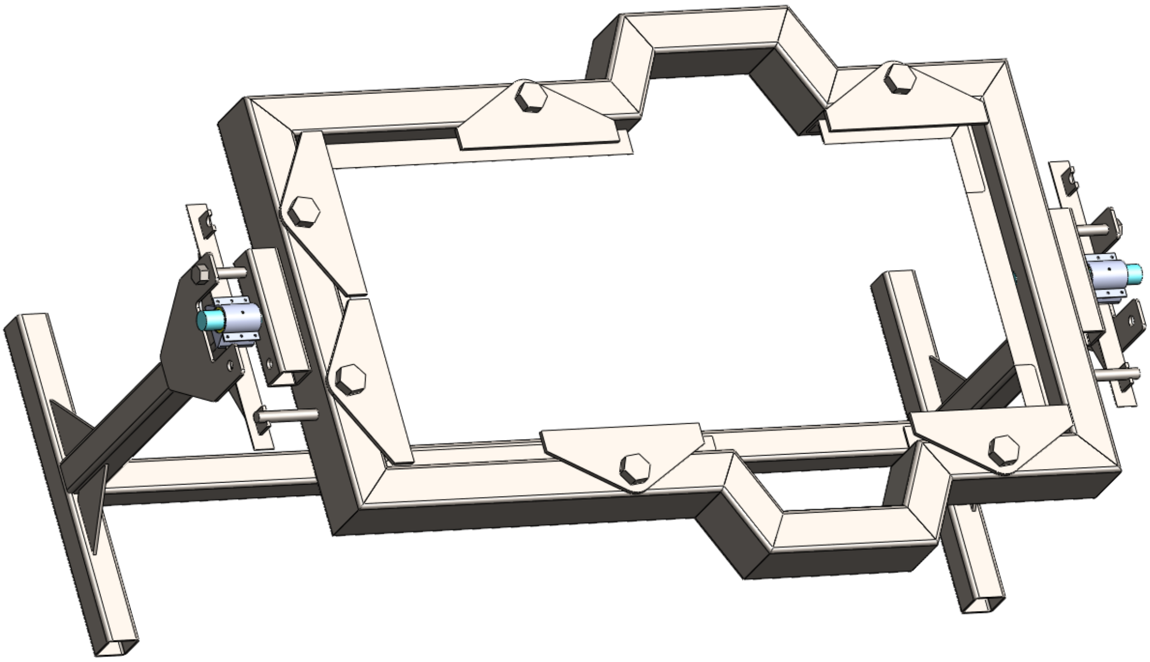
Figure 6. Structural table and its face A and B.



Detachable rotating plates will allow the plate to be fixed to the table using a stop on the heat exchanger plate, thus allowing the structure to rotate without disturbing the welding and joining process. See Figure 7.

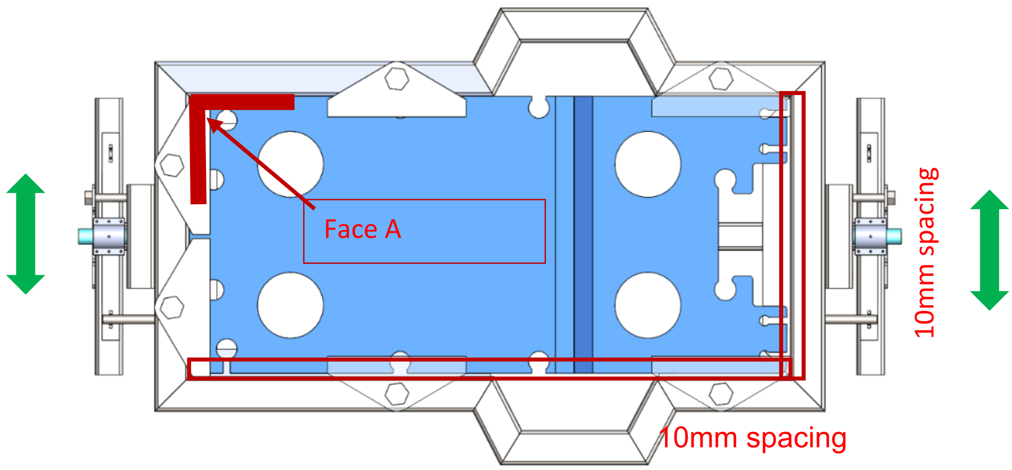
Figure 7. structural framework.





The structure will also have a brake, defined by a bolt that will be adjusted according to the position of the structure, either face A or face B. The objective of these brake bolts is to ensure that the table does not move when welding the plates. This manipulator design is oriented toward turning the plate by positioning the heat exchanger plate on the L-profile frame, to then be fastened with the clamping plates without tightening the recoverable, only keeping the plate in its position. To position the plate, it must be butted against the square frame at the top corner of the plate (on the opposite side of the anti-tip bars) so that the plate is always supported in two planes. The anti-tip bars are designed to prevent the table from turning 360°, thus preventing the heat exchanger plate from shifting to the other corner it is positioned on. This possible movement is because a 10mm gap was left between the plate and the frame of square profiles on the opposite extreme corner due to the volumetric expansion of the plate at the time of welding to avoid loads being exerted on the plate. Manipulative structure. See red arrows in Figure 8.

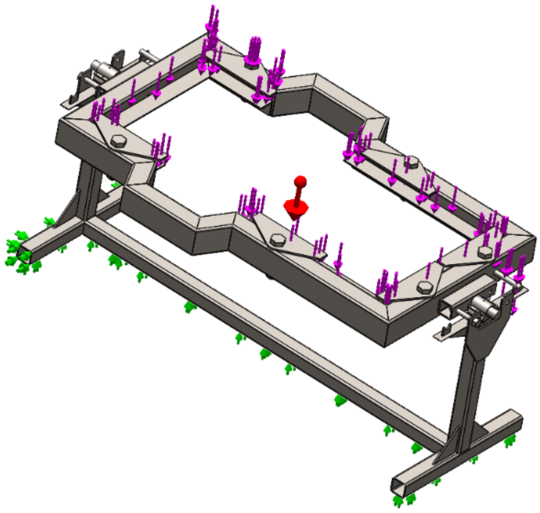
Figure 8. Position the plate on the manipulator table.



For flipping from face A to face B, remove the table brake bolts on opposite sides of the anti-roll bar and rotate, then reposition these brake bolts on opposite sides of the anti-roll bar. as in the previous case, this for both sides of the table. The green arrows represent this in figure 6. It is possible to enter the simulation stage of the handling system components with the finished design. The simulations are carried out considering the properties of the A-36 steel.

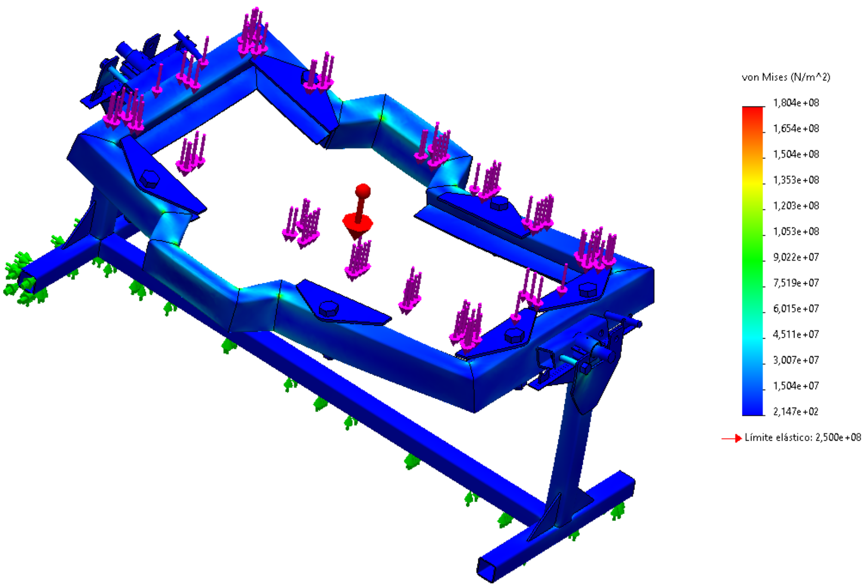
Vertical loads are applied to the table, simulating the weight of the heat exchanger plate, as shown in Figure 9.

Figure 9. Simulation.



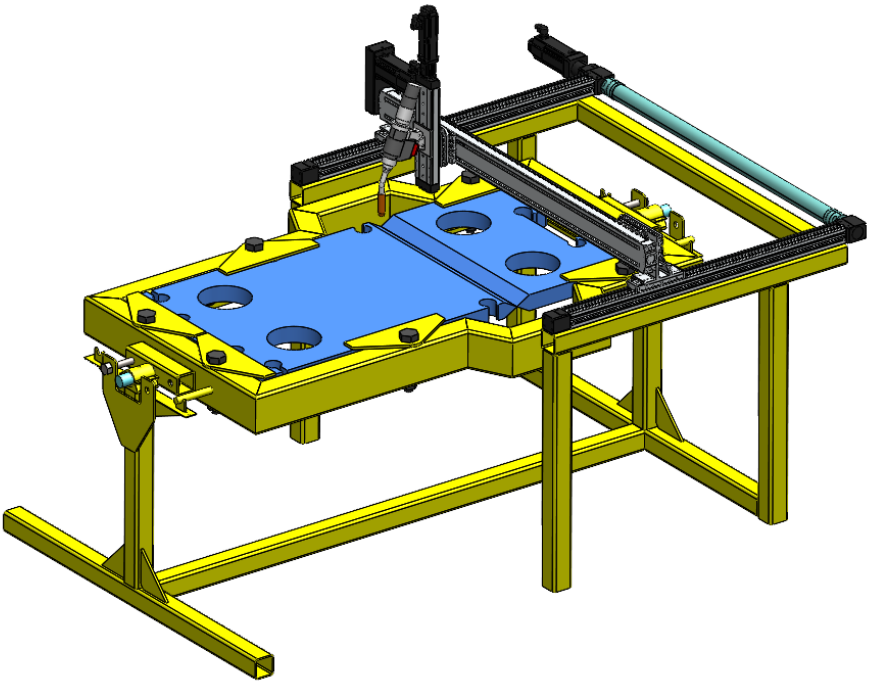
The working stresses are below the yield strength of the material.

Figure 10. Von Mises efforts



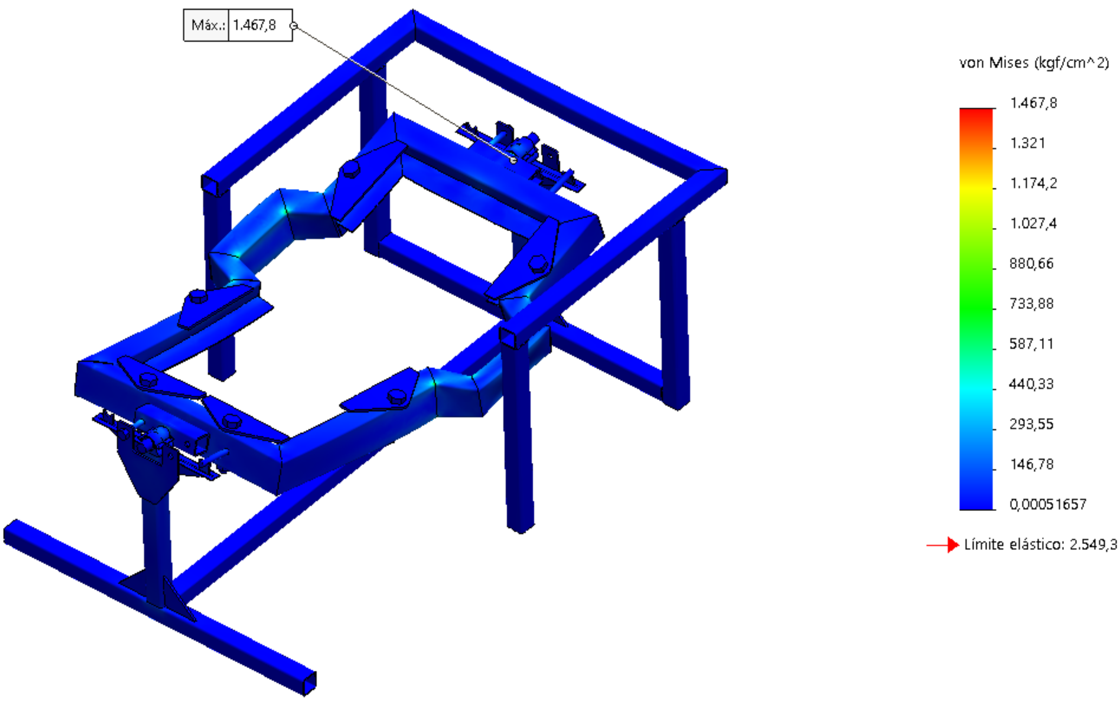
With the base defined and the elements for the rotation of the plate, it is, therefore, necessary to design the manipulator of the technique, which is developed through Bosch Rexroth products to design a 3-axis Cartesian manipulator. The manipulator is shown in Figure 11.

Figure 11. Manipulators to recover Heat Exchanger Plate



As can be seen in Figure 11, the welding manipulator consists of a Cartesian system that moves in its 3 degrees of freedom; X, Y, and Z. Due to the shape and lengths of the welding technique manipulator, a modification had to be made to the lower bench, whose analysis can be seen in Figure 12.

Figure 12. Von Mises efforts.



According to welding speeds, the first root beads take 13 min. Then the ten passes per side of 400 mm will take approximately 60 min. Therefore, within 1 hour and 20 min, the piece would be finished without operator interaction.

4. Conclusions

The methodology allows the development of a high-quality welding recovery technique that can be applied automatically by employing the technology's manipulators. In the case of the Termia company project, it was necessary to develop two manipulators, one to turn the large plate and the other to manipulate the welding technology and thereby ensure the correct application of the recovery. The created design of the structural system meets the requirements associated with the recovery technique, which are:

- The heat exchanger plate must be rotated horizontally to apply joint brazing.
- The structure must facilitate welding in the intermediate steps indicated in the welding procedure.
- The structure supports the own weight of the heat exchanger plate.
- The structure meets the stress and displacement requirements.
- The structure manages to rotate the plate, support its efforts, and hold it.
- The structure supports the weight of the technology manipulator included for controlling the torch path.

4.1. Limitations

The methodology presented has its main limitation that the components can only be recovered by welding or thermal projection, so the components must be capable of being weldable.
During the development of some recovery projects, they have been stopped due to the lack of stock in Chile of filler materials in the form of tubular wire.

4.2. Future Works

For future work, the following challenges or lines of work are proposed:

- Development of low-cost anthropomorphic manipulators that allow the development of more complex trajectories.
- The study of the plasma transferred arc (PTA) welding process in order to be able to use mixtures of powders that involve different materials.
- The development of a mini-manipulator (end-effector) allows adding other functionalities to the welding process.

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9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

OBJETIVOS DE DESARROLLO SOSTENIBLE