FAILURE ANALYSIS OF A STAINLESS STEEL STRIP ACCUMULATOR OF AN ANNEALING AND PICKLING LINE*

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Abstract
The annealing and pickling line n. 1, responsible for the production of stainless steel 3xx, 4xx and 430a in thicknesses from 4 to 0.4 mm, has two vertical strip accumulators. These are intended not to let the material exceed the determined time in the furnace and in the pickling, and consequently do not cause defects like burning and excessive pickling. Strip accumulator n. 1 avoids the line from stopping during welding execution of the coils in the welding machine. In sequence, the strip accumulator n. 2 avoids the line from stopping at the end cutting of the tips, and in the coils removal from the pickling. The strip accumulators have a roller table that during the strip accumulation moves vertically downwards while its counterweight moves vertically upwards, and do the inverse movement when the material is released. On December 12th 2018, the failure occurred in the strip accumulator n. 1, where it was verified that the shaft of one of the pulleys had been fractured by high-cycle mechanical fatigue, which was characterized by alternating bending. With the fracture of the shaft, occurred the unevenness of the counterweight that damaged the guides. Failure analysis of this occurrence was based on the PDCA methodology, when was verified a weld between the shaft and the pulley. The analysis of the microstructure transformation in the molten zone, in the heat affected zone and in the base metal was carried out in an optical microscope, and no abnormality was observed. It was also carried out the end test by penetrating liquid, finding an inadequate weld in its geometry, as well as longitudinal trunks along the center of the weld bead. However, after a huge investigation of the causes, it was found that the failure was triggered by an inadequate design of the pulley shaft. It was also verified that the shaft had an open measure, inadequate for the operational context. After the analysis, action plans were drawn up based on the FMEA methodology to inhibit the failure recurrence.
Keywords: accumulator, fatigue, welding..

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1 INTRODUCTION

When the globalized economy emerged, was observed an increase in the demand for products and systems with better performance and competitive costs [1].
Simultaneously, appeared the necessity of decrease the chance of failures in products, which resulted in an increasing emphasis in its trustworthiness [1].
To exert its strategic position, the maintenance must be focused on business results [2].
Mainly it is necessary to stop being efficient to become effective [2]. In other words, it is not enough just to repair the equipment or to install it as fast as possible, but it is necessary mainly to keep its function available for the operation, reducing the non-planning production stopping chances [2].
The annealing and pickling n.1 line, responsible for the production of 3xx, 4xx and 430A stainless steel in thicknesses from 4 mm to 0,4 mm, has two vertical strips accumulators. Considering that these aim do not let the material inside exceeds the determined time into the furnace and chemical pickling, and consequently do not to bring on burning defects and excessive pickling. Strip accumulator n. 1 avoids the line from stopping during welding execution of the coils in the welding machine. In sequence, the strip accumulator n. 2 avoids the line from stopping at the end cutting of the tips, and in the coils removal from the pickling. The strip accumulators have a roller table that during the strip accumulation moves vertically downwards while its counterweight moves vertically upwards, and do the inverse movement when the material is released.
The figure below pictures the strip accumulator n.1:

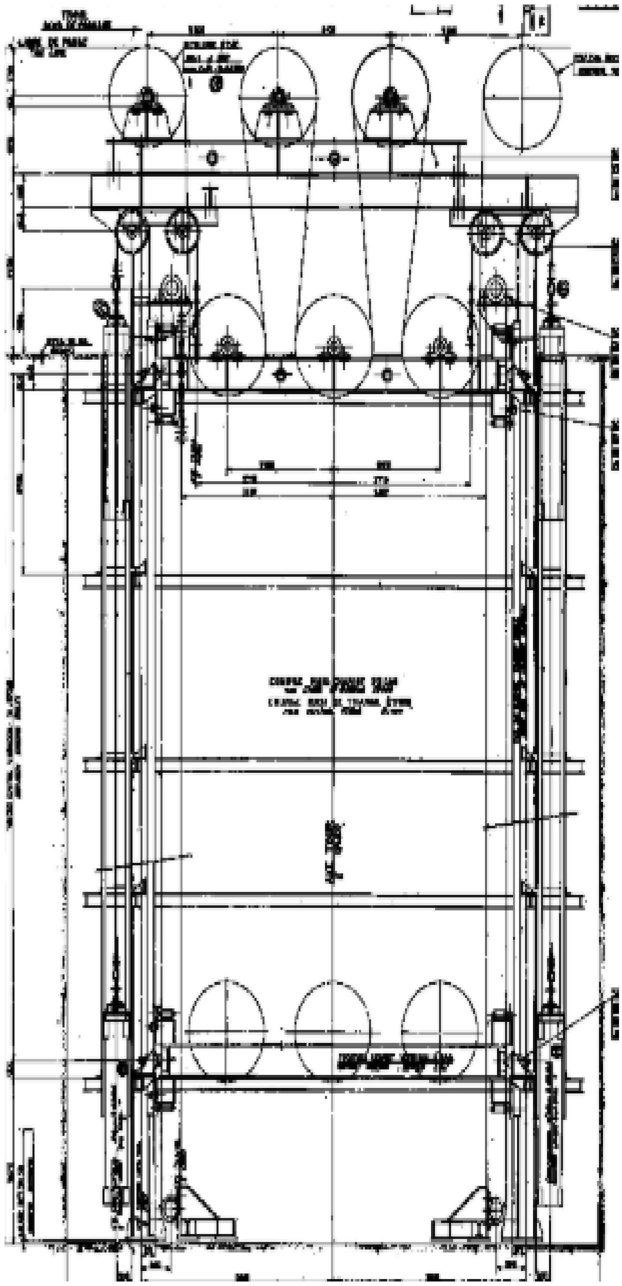

Figure 1. Strip accumulator n.01

2 MATERIAL AND METHODS

This failure analysis was performed on the annealing and pickling line n.1, in strip accumulator assembly n.1.
After the shaft break of one of the pulleys counterweight, one of the steel cables broke and occurred the plastic deformation of the guides, in such a way as to preclude it from operating within its operational context.
For this failure analysis, was used the PDCA 5 whys methodology.

The table below exemplifies the PDCA 5 whys methodology [3].

Steps	Answer contains	Question examples
What	Necessary actions to the analyzed theme	-What should it be or is being done? -What are the inputs to the problem / process? -What do you want to extract from this problem / process? -What methods, materials and technologies should be used?
Why	Actions explanation	-Why does this problem occur? - Why is running this way? -Why do you have to deal with this problem?
Where	Sites influenced by actions	-Where does the problem occur? -Where is necessary to act to correct the problem?
Who	Responsibilities for actions	-Who are the agents involved? -Who knows the process better? -Which people should carry out the action plan?
When	Set deadlines	-When to start and end? -When should each step of the plan be executed?
How	Methods to be used	-How will the plan be executed? -How to record the necessary information? -How to define the stages of the process?
How Much	Set budget	-How much will the cost involved? -How much will the necessary resources cost? -How much does it cost to correct the problem?

Tabela 1. 5W2H methodology

In addition to the use of 5W2H was also used the PDCA methodology. The PDCA cycle, also known as Shewart cycle or Deming cycle, was introduced in Japan by Shewart and diffused by Deming in 1950 [3].

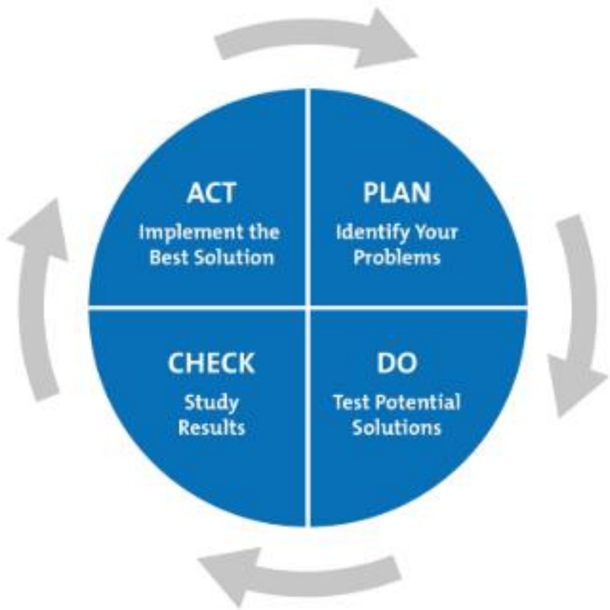

Figure 2. PDCA cycle.

3 FAILURE ANALYSIS

On December 10th 2018 occurred the spindle breakage of the pulley carriage of the counterweight belonged to the strip compensation car n.1.

Figura 3. Spindle breakage

This break caused the fall of the counterweight on its guides. It caused the plastic deformation of these around the counterweight, in such a way as to make it impossible to move in the positive and negative direction of y axis. It can be seen in the figure below.

Figure 4. counterweight drop

Detail of the counterweight drop on the guides:

Figure 5. Detail of the counterweight drop

To begin the failure analysis, the 5W2H methodology was used to understand this phenomenon, and it can be seen in the table below:

Characterization of the Phenomenon: Misalignment of stainless steel plate on December 10th 2018, leading to a line stop for 107 hours and 22 minutes. This failure occurred in the RB1 input strip accumulator. This problem is not related to the ability, having a low tendency of occurrence. Due to the breakage of the pulley shaft of the steel cable, there was unevenness of the output balance, and in the last 9 years this failure model has occurred just once.	
Problem Identification	
5W2H	
(What?) What identifies the problem?	Misalignment of stainless steel sheet.
(When?)When did the problem occur?	10/12/2018, carrying on a stop of 107 hours and 22 minutes.
(Where?)Where did you see the problem?	RB1 inlet strip accumulator.
(Who?) Is the problem related to the skill?	No.
(Which?) Which is the trend?	Low trend.
(How?) How is the state different from normal?	Breaking of the pulley shaft, in order to trigger the unevenness of the counterweight of the output.
(How many?) How many times does it happen?	In the last 9 years this failure with this model of failure has only occurred once.

Table 2. Application of the 5W2H methodology

Subsequently, the 5-way methodology was used to determine the root cause.

1st Why:

Why did RB1 had a 107-hour shutdown?

A: Because the stainless steel sheet was misaligned in the entrance LOOP of RB1.

2nd Why:

Why was the stainless steel sheet misaligned in the LOOP of the RB1 inlet?

A: Because the roller table strips accumulators were with a load unbalance.

3rd Why:

Why did the roller table strip accumulators were with a load unbalance?

A: Because the steel cable counterweight of output LOOP on LO side was not level with the LA side.

4th Why:

Why was the steel cable counterweight of output LOOP on LO side not level with the LA side?

A: Because the pulley shaft of the counterweight steel cable guide was broken.

5th Why:

Why did the counterweight steel cable guide pulley break?

A: Because the shaft was welded to the sheave, which caused the shaft to weaken in the region of the weld in order to break through fatigue.

The fatigue fracture can be seen in the figure below:

Figure 6. fatigue fracture

6th Why:

Why was the shaft welded to the pulley, which caused the shaft to weaken in the region of the weld in order to break through fatigue?

A: Because the weld has generated a tension concentrator so as to core the crack, propagate and fracture the shaft.

-Remaking the 6th why in search of the fundamental systemic cause:

6th Why:

Why was the shaft welded to the pulley?

A: Because the design of the shaft assembly with the pulley does not provide interference fit, which allows the pulley to move against the bearings.

It was soon found that the fact of the weld on the shaft was due to a poor design that did not predict a shaft with interference. As can be seen in the figure below, the 80 mm shaft has an open measurement:

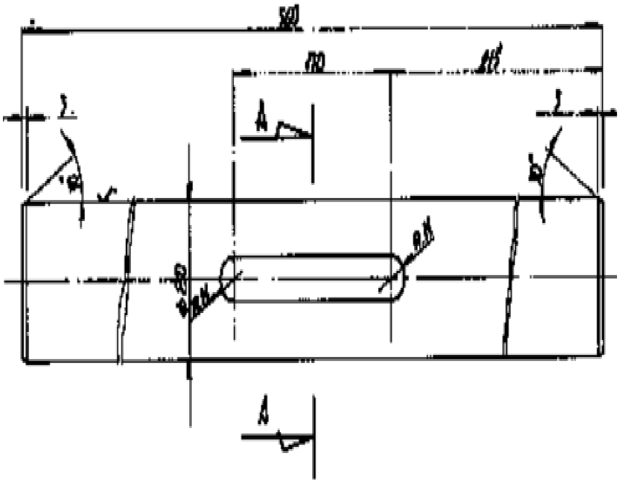

Figure 7. Pulley shaft with open measurement

To eliminate the fundamental cause, the following actions were taken:

Action 01: Re-establish the loop car operating conditions.

Action 02: Perform END on the other axes of the car loop of the input and output.

Action 03: Revise shaft and pulley designs by changing assembly adjustments to interference condition to prevent pulley from moving.

Action 04: Generate PM to make END on pulley shafts every 4 years.

Action 05: As an opportunity to generate PMs also to inspect the bearing securing bolts and bearing caps.

Action 06: To program the replacement of all pulleys and axes of the input and output loops.

4 RESULTS AND DISCUSSION

After 107 hours of productive flow parade the operating conditions were reestablished.

It was verified that the fracture by fatigue was by rotary bending [4].

Cracks were observed along the entire circumference of the weld after application of the non-destructive test by penetrating liquid.

Application of penetrating liquid method:

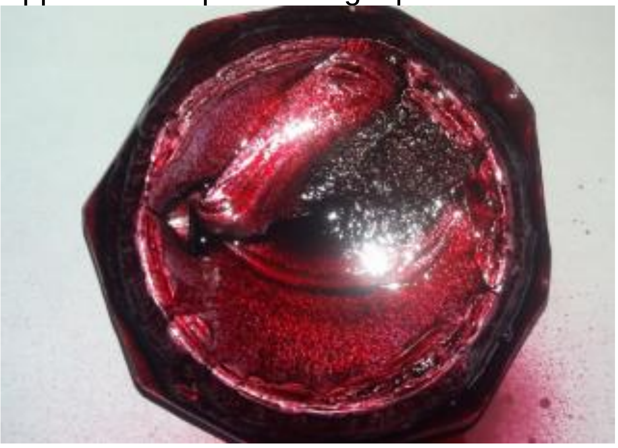

Figure 8. Application of penetrating liquid

After applying the revealing, it was possible to verify the existence of cracks:

Figure 9. Revealing application

Since the shaft material used 1045 and the electrode used the E7018, it was expected that the beginning of the crack would have been due to the microstructure transformation of the material in martensitic structure, in order to weaken the weld bead.

To verify if it was true, the analysis of the microstructure was done.

The first analysis was of the base metal, verifying a predominantly austenitic microstructure:

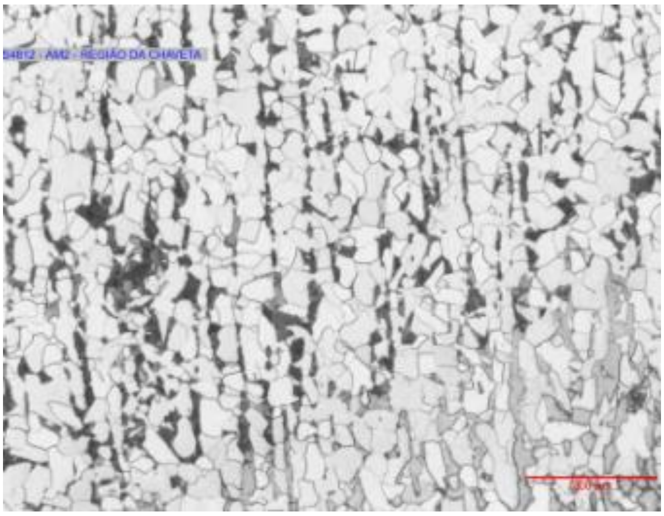

Figure 10. Austenitic microstructure

Then, the analysis of the melted zone and the heat affected zone was carried out in search of martensitic formation:

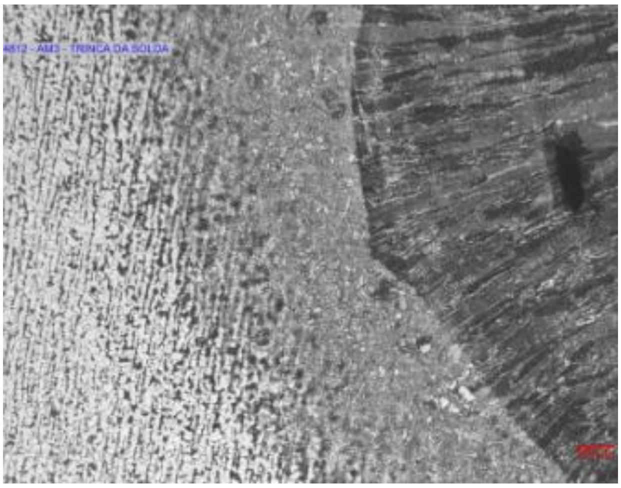

Figure 11. Heat Affected Zone

It was verified the absence of matersite in the heat affected zone, discarding the hypothesis of the microstructure transformation.

The crack nucleation was verified by fatigue due to the concentration of the stress on the weld bead with an irregular surface. It performed the perfect host for tension concentrators, the main responsible for the nucleation of crack by fatigue.

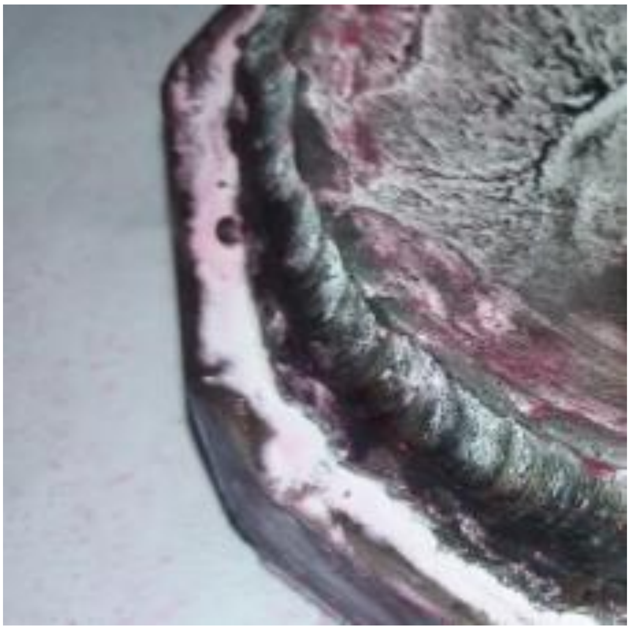
Figure 12. Welding as a tension concentrator

5 CONCLUSION

With the emerging industry 4.0, and the continuous increase in the competitiveness of industries for the market share, it becomes necessary to produce more and more with the minimum possible costs.

A pillar for any industrial segment is the reliability of its equipment, with failure analysis being one of the most powerful tools to avoid recurrence of failures, and as laterality avoiding common joint failure.

It is expected that this analysis will avoid the recurrence of failure in the strip accumulator of the annealing and pickling line n.01.

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