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Scientific Method applied to Failure Analysis on Engineering Components

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Abstract

Shank adapters or start bars are slim parts of hardened steel used in rock drilling hammers for the mining industry. This extreme type of work occasionally generates premature failures to the bar because of the heavy-duty working conditions.
In the present case, we will analyze the study of a bar, which has fractured suddenly and prematurely near the center of the piece. We are looking for an accurate method to detect the causes responsible for the problem applying the Scientific Method as a strategic tool to perform each of the steps in an orderly manner, without risking possible solutions prematurely or discarding hypotheses that seem unlikely at first sight.
It has been performed a detailed study including part design, material, and working conditions, considering all possible combinations of cause and effect that may influence the final result, and considering the same using a Pareto analysis.
Methodical analysis is supported by actual experience through performance of mechanical tests, computer simulation of stress and fracture analysis through macroscopy and optical microscopy. From the results obtained, it was found that to suit the type of material used by the manufacturer, the adjustment of the variables in the heat treatment and certain geometric details in the construction of parts are essential to achieve the desired results, optimizing perforation work.

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Keywords: shank adapters; mine; rock; rupture; failure; analysis.Introduction

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1. Introduction

In this case, failure analysis is applied to find the possible cause(s) that explain the failure while using a start bar or shank adapter. This method is important to determine the causes of failures in an adequate and systematic way in order to propose necessary corrective actions to avoid the repetition of accidents that may cause material loss and eventual injuries on people. This method can also be applied to optimize design, obtain a longer useful life, increase reliability, or decrease manufacturing costs.

Figure 1 shows the shank adapter design, the object of study. The hexagonal end couples with the pneumatic hammer, and an extension added in threaded part, where the drill bit is mounted.

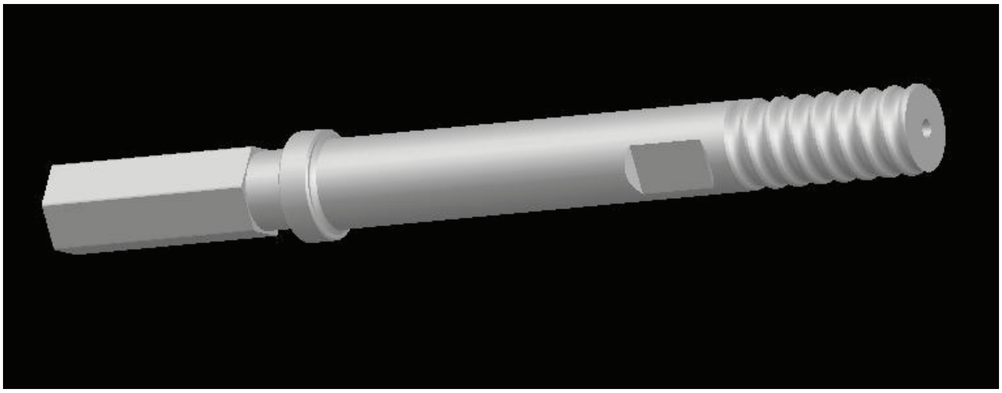


Figure1. Start bar or shank adapter diagram.

The drilling process is performed as follows: Hammers are coupled with an auxiliary arm, which is the telescopic pushing mechanism that keeps an adequate pressure and forces the drill to advance; they are known as telescopic arms.

Basically, they consist on a pneumatic drill articulated with a steel guide or mast that, when articulated through pneumatic or hydraulic means, it spins goes up or down along the mast. The number of positions is unlimited.

Once mounted on the telescopic arm, the hammers work with a piston that moves in a reciprocating manner within the hammer cylinder hitting the drilling shank adapter in each complete cycle; the energy is transmitted by the shank adapter to the drill bit through couplers and extension bars, which at the same time, hit the rock. Rock fragments are removed through an internal coaxial duct in the shank adapter, in this case called circulation or blowing ducts.

2. Materials and Methods

The methodology used is the implementation of a structured analysis based on the scientific method and adapted to this discipline with specific procedures. The techniques used are fractographic analysis, microstructural analysis, hardness and microhardness testing. Different methods of Cause-Effect analysis were use: Brainstorming, Pareto Chart, Ishikawa Diagram and the 5 Whys.

The material used is the shank adapter, object of study. The tools used for making observations were: Celestron Digital Microscope Model 44306, Olympus Metallographic Test Bench Model PME3, King Rockwell Hardness Tester and Leitz Microhardness Tester.

For Computer Simulation, CAD software (Solid Works Simulation in Solid Works Premium 2012) was used for the in-detail analysis of the strength distribution.

3. Development

3.1 Previous Inspection, Material Composition and Manufacturing Process

The analyzed shank adapter was received in two parts (A and B), as shown in Figures 2 and 3.

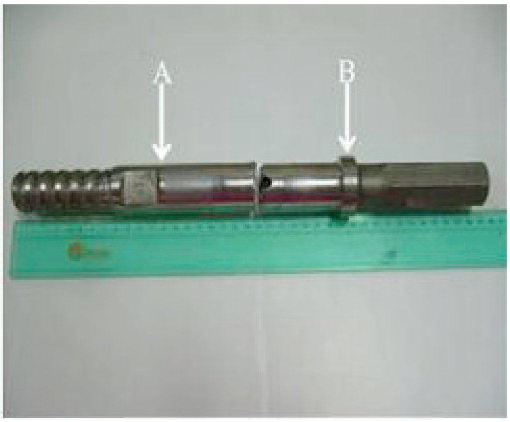


Figure 2. Broken shank adapter.

Figure 3. Fracture area.

The object of study is a SAE-3310 steel bar with a 1.2 mm. layer generated by a case hardening heat treating. In Table 1, the chemical composition of the material is detailed.

Table 1. Chemical composition.

% C	% Mn	% Si	% Cr	% Ni
0.08 / 0.13	0.45 / 0.60	0.20 / 0.40	1.40 / 1.75	3.25 / 3.75

The information collected about the piece manufacturing process is present on Figure 4.

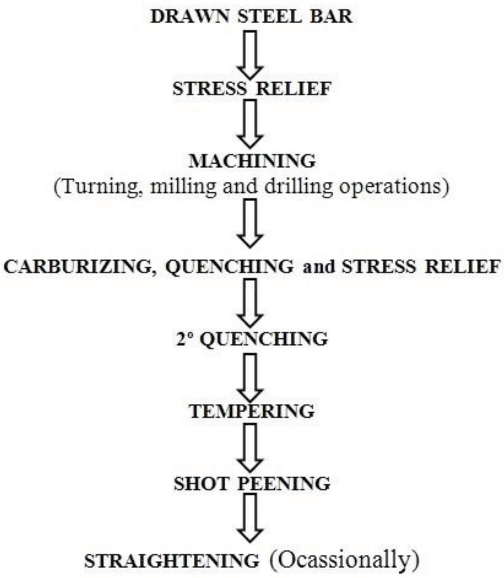


Figure 4. Shank Adapter Manufacturing Process.

Dimensions and simplified model are shown in Figure 5 and 6. In its design, the shank adapter has a centered hole along the piece´s axis and a transversal perforation connected with the centered hole. These perforations are used to let water inside and have the function of removing the shredded material around the bar. The fracture is produced in the intersection of these two perforations.

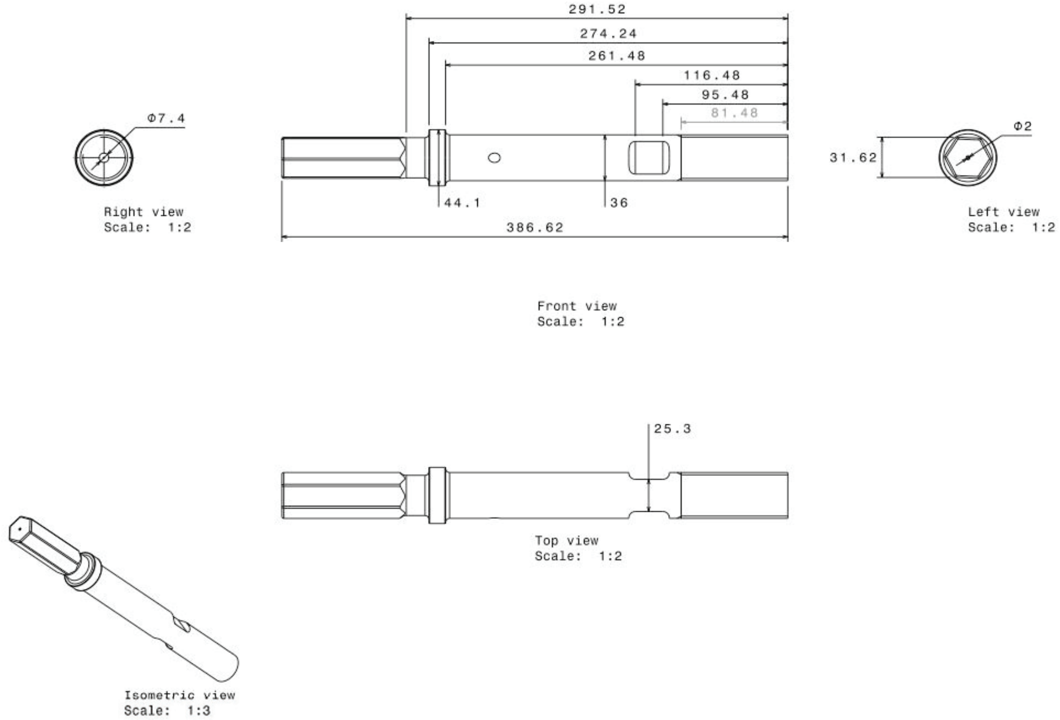


Figure 5. Shank Adapter Diagram.

The tridimensional modeling design was based on a technical drawing with the dimensions of the object of study. The corresponding material found in the program database was applied. Then, it was collected the operating data - including regular operating movement types, speeds and pressures, so the loads to be applied to the model could be deduced. An analysis was made using the finite elements method on the loads and restrictions of mobility of anchorages of the parts in their working environment in real life. This determines specific clamping types of the part based on the computer model and determines tensile strengths generated in the whole part produced by loading and clamping. This way, the most concentrated stress areas were found. These areas have the highest chances of material plasticization due to effort magnitude, where material brittleness and later failure occurs.

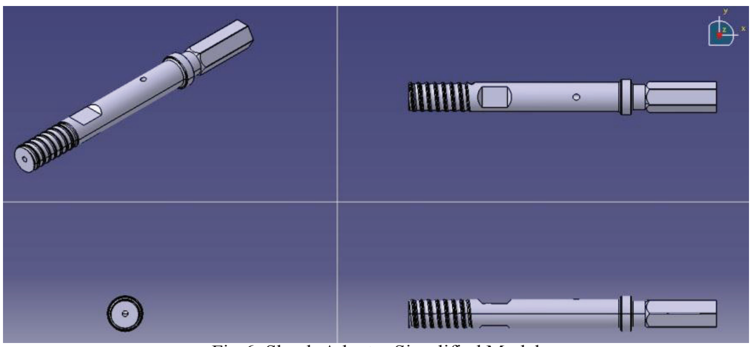


Fig.6. Shank Adapter Simplified Model

3.2 Fractography

The fracture propagated following two successive processes; those influence regions are signaled in Figure 7. A) origin of stress fracture, B) stress concentration effect produced by the perforation roughness C) brittle fracture with quick propagation.

Figure 7. Fracture Surface Area.

3.3 Metallography

Figures 8 to 10 show the microstructure present in different areas of the sectioned piece.

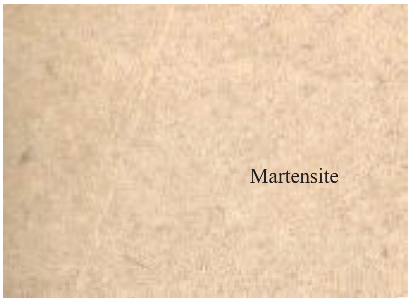


Figure 8. Surface x100 Image – Martensite

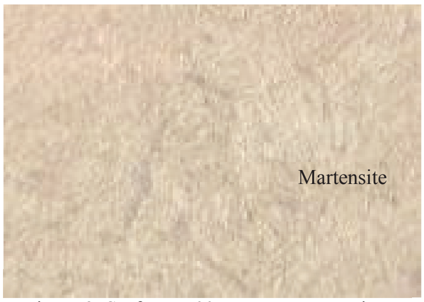


Figure 9. Surface x500 Image – Martensite

Figure 10. Core x500 Image – Bainite.

3.4 Hardness Analysis

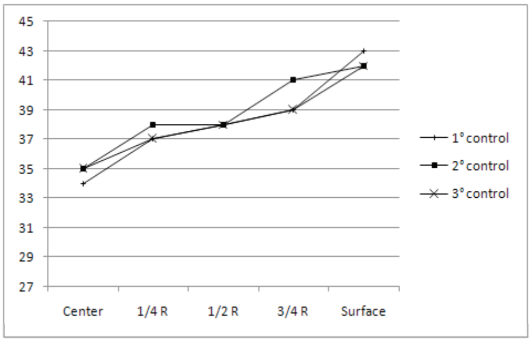


Figure 11. Microhardness profile in hole of the fracture area.

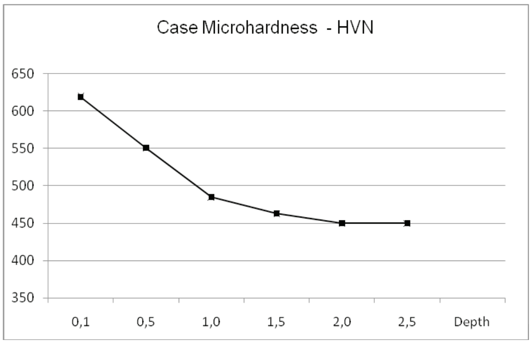


Figure 12. Microhardness profile in outer diameter.

It can be observed in Figures 13 and 14 that although hardness is reduced towards the center, the core hardness is higher relative to the expected value in this kind of steel.

3.5 Tensile Forces Simulation

Simplifying assumptions were made in order to reduce the analysis and calculation time, increase the comprehension of the problenm and the result´s quality. These were:

A static load was applied, although it was a dynamic and cyclical load, taking into account the maximum value of the force supported by the component; the maximum tensile forces will be achieved because during the rest of the cycle, the values are always lower. This force acting on the piece was calculated as the maximum compressed air pressure applied by the pneumatic hammer, multiplied by the piston section that moves jointly with the shank adapter, 0.63 MPa x 968 mm^2 equal to 11133 N. This force is taken as an example because tensile forces are proportional to the load between Hook´s law limits; therefore, this analysis is performed to identify the regions in the part wich suffer the maximum stress concentration. Because of that, the magnitude of the reeal force is no relevant to make the qualitative present study.
The material used for modeling the part was SAE 1010 steel, although the real steel of the piece was a SAE 3310. Because this simplifying assumption is valid in both steels below the yield point where both have the same Young Modulus (or elastic modulus) because this value is the same for all kind of steels and it is the only important parameter in this analysis.
Clamping regions are considered as perfectly rigid fixtures; however, in the real life, clamping areas and couplings cannot be perfectly rigid, but it is a simplification automatically made by the calculus program to avoid high complexity.
The figures 13 and 14 show the boundary conditions of the loads and fixtures of the simulation model.

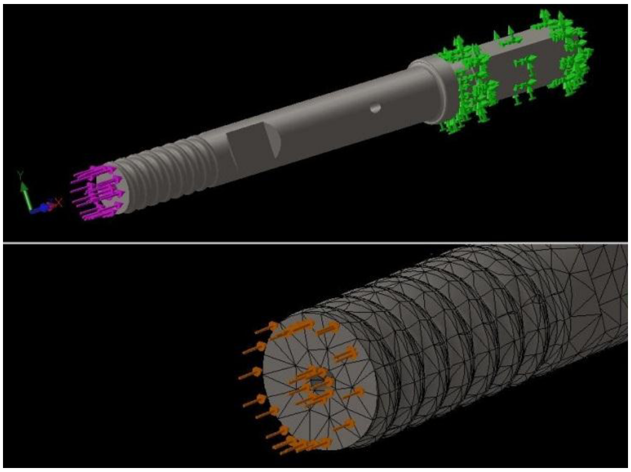


Figure 13. Loads.

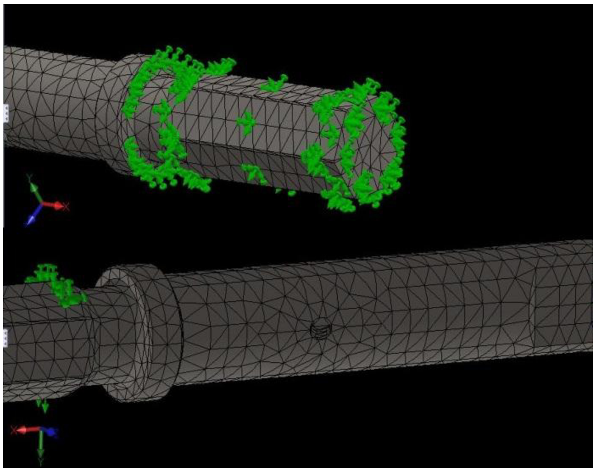


Figure 14. Clamping and Meshing.

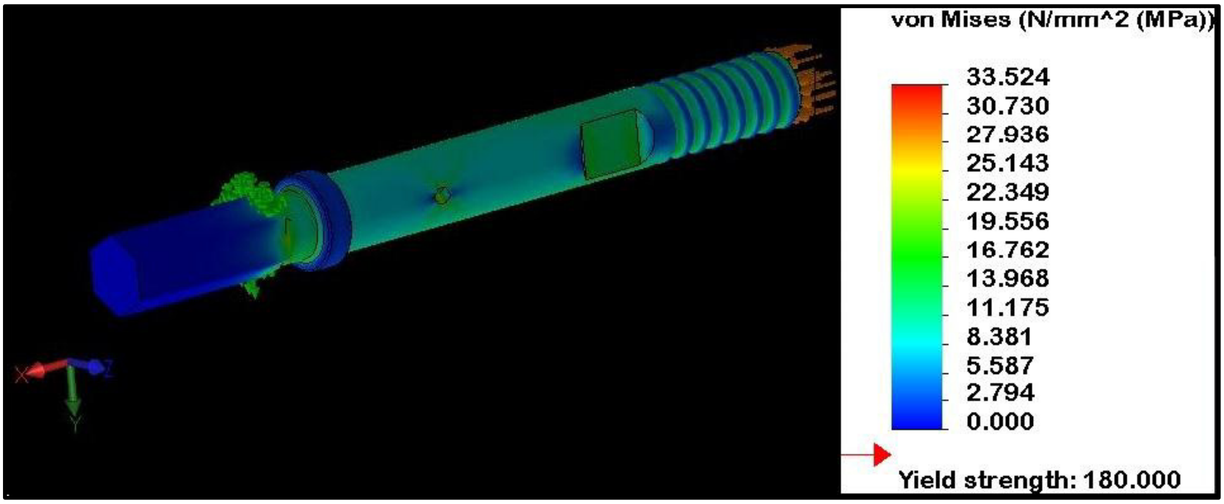


Figure 15. Effort Simulation Results

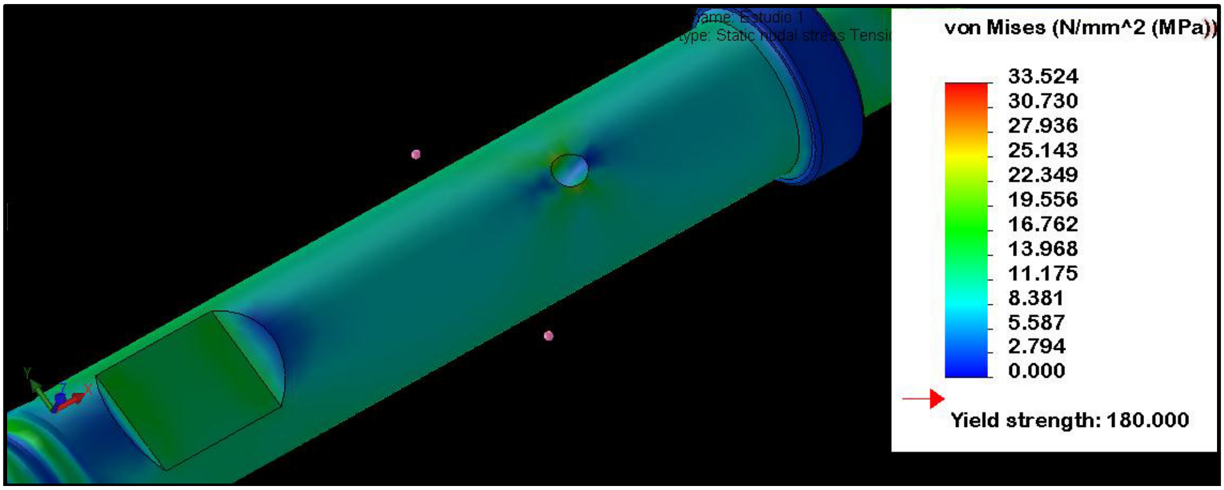


Figure 16. Von Mises Yield Criterion Maximum Concentration

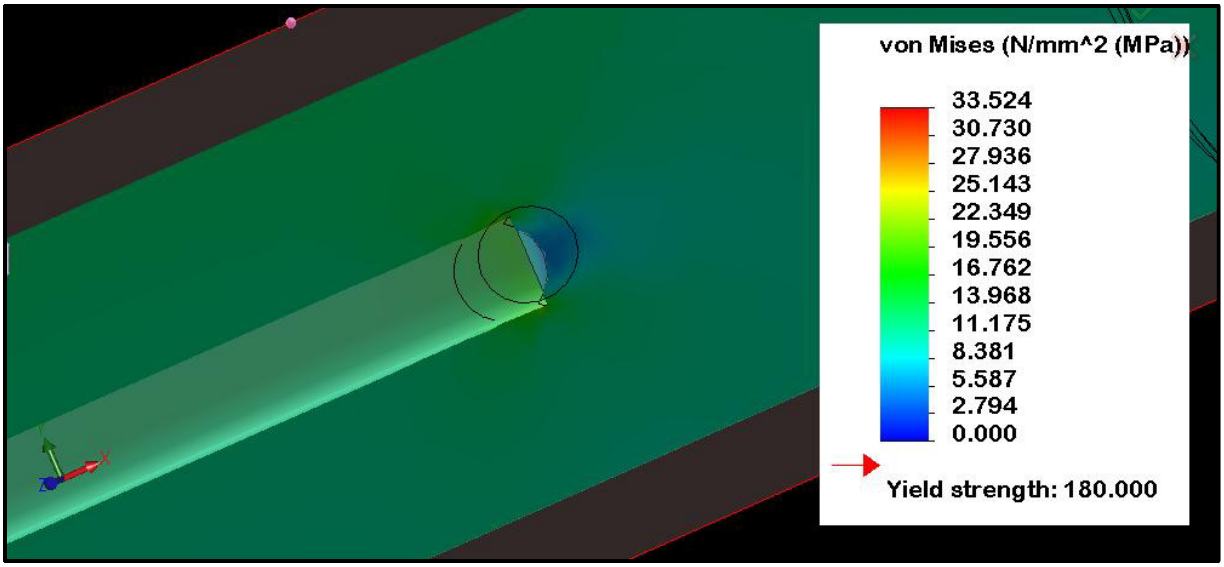


Figure 17. Longitudinal Section of the Mid Plane

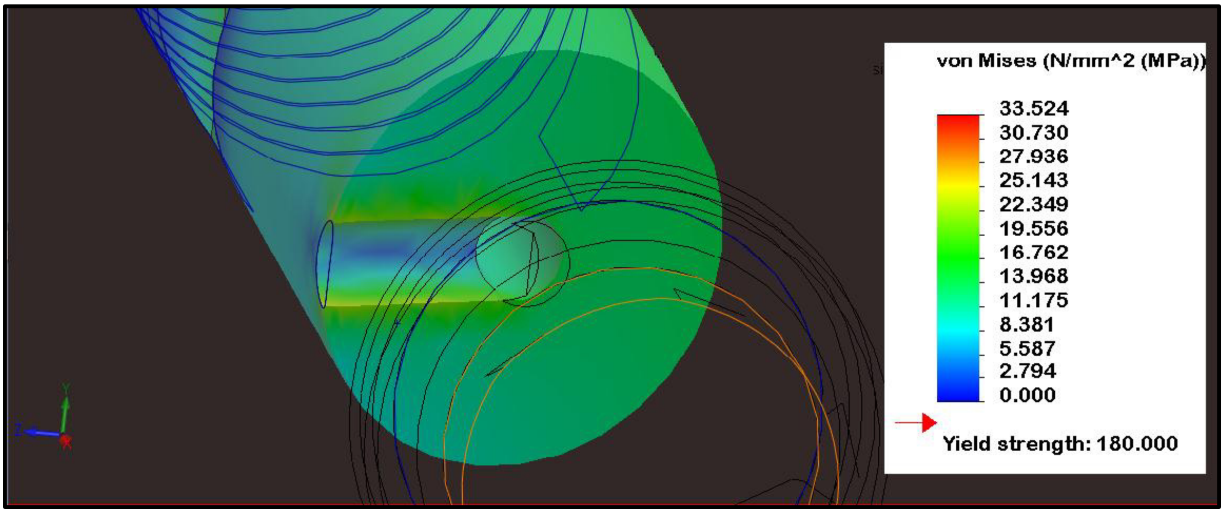


Figure 18. View of the intersection of the lengthwise and diagonal holes.

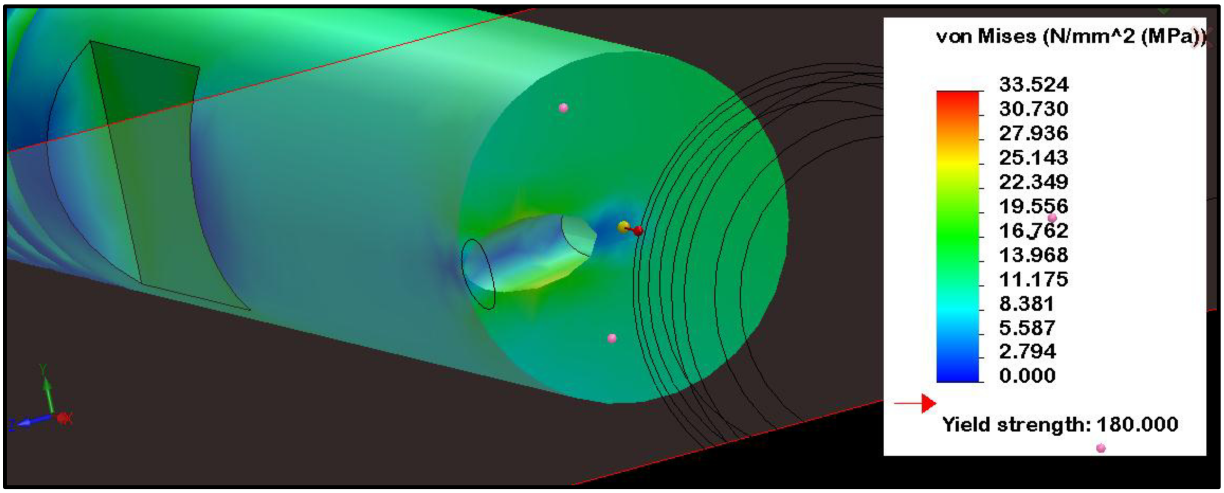


Figure 19. Cross Section at 60mm of Mid Plane, Perforation Intersection. (Stress Concentration)

In Figures 15 to 19, it is observed the piece that works with flexocompression. Stress concentration occurs in perforation because the area is smaller in this section, and the load is constant, tensile force increases in this place of the shank adapter.

4. Results and Discussion

It has been thoroughly analyzed the manufacturing method of the shank adapter taking into account the 5M method. In Figure 20, it can be seen the Ishikawa Diagram.

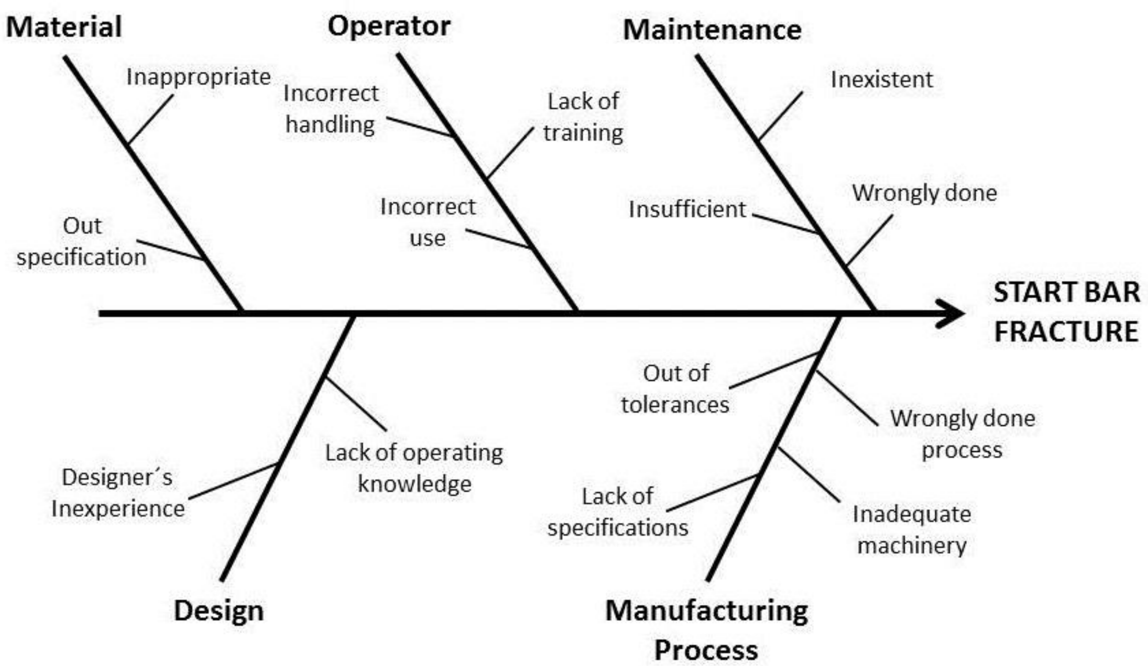


Figure 20. Ishikawa Diagram.

Some variables that could be the causes of the fracture were rejected after a particular analysis of each case, so they are not considered to be origin of failures. These are:

The material has gone through a quality control process previous to product manufacturing where a chemical analysis corroborated the composition, and raw material is deleted as the cause of the failure.

The operator's ability is not a factor that could justify a failure given the characteristics of the equipment where the start bar is mounted; the inadequate use of the tool is also deleted.

Maintenance of component and machinery used is preventive, adequate and sufficient. This way, parameters to be considered as factors influencing component failure are those related to design and manufacturing process.

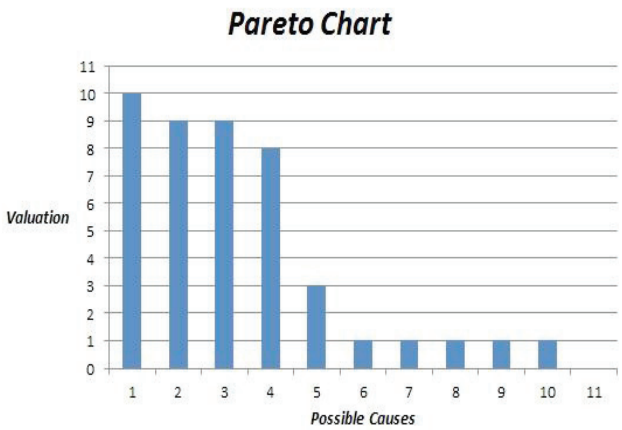
Part Design: In technical drawings and because of the loading and clamping, it can be appreciated a stress concentration in the area around the intersection of the two perforations of the part (between the axial or longitudinal and the radial or diagonal). Through effort simulation with FEM, it can be seen that the assumption is correct because the ultimate tensile forces present in the piece are symmetrically located on both sides of the union section between the two perforations. It is evident that this sector of the piece that has the most probability of plasticization and following material cracking.

Manufacturing Process: Surface roughness of the holes is high, and a very irregular the surface finish observed.

During the hardening and tempering treatment, the part perforations were not covered, so a rich-in-carbon layer was created inside, being the thickest in the cross section between the perforations.

Because the slenderness piece, there is a tendency to deformations during heat treating, and these must be straightened with a hydraulic press after the hardening process. This operation has the high risk of microcrack generation inside the perforations or in the surface of the piece, which generates important stress concentration effects.

After analyzing this case, it is concluded that there are possible causes more relevant than others, so a Pareto Chart was created (Figure 21) where it is reflected the valuation of the possible causes of the shank adapter failure.



	Possible Causes	Valuation
1	Design. Hole acting as tensiles forces concentrator.	10
2	Roughness after machining process. (perforation)	9
3	Heat treatment. Hardening into the perforation.	9
4	Straighten. Generation of microcracks and embrittlement.	8
5	Working environment.	3
6	Out of specification wire drawing.	1
7	Out of specification hardening.	1
8	Insufficient shot blasting.	1
9	Insufficient stress relief.	1
10	Tempering time.	1
11	Irregular surface finish.	0

Figure 21. Pareto Chart.

After making the Pareto Chart, it is found that the failure of the shank adapter is related to the combination the most of one causes, to a greater or lesser degree, the main causes are:

- Deficient design. Perforations have a stress concentration effect.
- Roughness after the machining hole process. (Drilling).
- Hardening into the hole.
- Straightening after the hardening. (Appearance of micro-cracks)

5. Conclusion

After heat treating, the hardened is generated inside the holes. This high hardness layer with low ductility increases material brittleness. Stress concentration induced by the geometry of the piece, particularly in the holes intersection, added to the high roughness in the hole surface induced the generation of microcracks during the straightening process of the piece. This small internal defects origin an evolving crack due to the cyclic stress applied in the use of the piece producing a typical failure fatigue propagation mode.

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