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FAILURE ANALYSIS OF A TRUCK SHAFT

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Abstract. *This work aims to study the causes that led to the nucleation and propagation of fatigue crack in axis of a truck used in the process of eucalyptus extraction, evaluating the possible causes and defects that led to the event. Traditional methods of analysis such as visual inspection, metallographic tests and Rockwell B hardness tests were used. With micrographs, the difference between the heat-affected zone and its metastable phases, the phases present in the filler metal and the base metal was easily observed. The results presented by the hardness test showed that the microstructure formed in the molten zone presented higher hardness. The tests performed indicate the shaft failure from the fatigue mechanism.*

Keywords: *failure analysis, fatigue mechanisms, transmission shaft, metallography, HAZ.*

1. INTRODUCTION

Fatigue is a complex phenomenon that has not yet been much studied, characterized by the gradual and slow development and propagation of cracks, which results in the catastrophic failure of the component. Responsible for most mechanical element failures, it is of extreme importance in the process of idealization of machines and structures, since the failure by this phenomenon can occur in voltage levels below the limit of tensile strength or the limit of resistance to flow. According to Budynas and Nisbett (2016, p.269), when the parts fail statically, they generally develop a very large deflection because the stress has exceeded the limit elástic deflection, so many static faults give visible warning before the fracture occurs. In this way it is possible to correct the problem before failure occurs, other than the fatigue failure that does not signal, so it is sudden and total. There are several factors that can trigger the formation and propagation of cracks, such as: type of loading, type of geometry, microstructure of the material, environmental factors, residual stresses and surface finish from the manufacturing processes.

The study in this area is justified because a sudden failure of a mechanical equipment like the axis of a cart can cause an accident, putting human lives in danger, as well as cause total or partial unavailability of the equipment. As stated by Mirshawa and Olmedo (1993), corrective maintenance costs, or what is also called emergency maintenance, are often only a small part of the costs generated, corresponding to labor costs, tools and materials used, most of the cost with this type of maintenance is due to the unavailability of the equipment. Greater understanding of the area in project design can prevent such events from occurring

Similar studies have already been developed by other authors where they sought to understand the influence of notches in the fatigue process. In his research Peres (2008) determined that notches have a determining role in life to fatigue, in the study equipment, the increase of notch radius could increase considerably component life. The present work aims to study the factors that cause the nucleation and propagation of fatigue crack and also to evaluate the possible causes and defects that lead to the axis of a truck used in the eucalyptus extraction process, highlighting these factors is important for corrections to be made and it is possible to extend the useful life of the shaft.

2. METODOLOGY

The material analyzed is an axle of the semitrailer used for tritrem forest cargo transport. Figure 1 shows the axis as received for analysis.

Figure 1. Semi-trailer axle used to transport forest cargo tritrem. Source: Authors.

Fault analysis was performed by a fault analysis technique, also known as FTA (Faut Tree Analysis). The FTA is a tool that can be called deductive where, that is, from an initial event, which we want to analyze. It identify the intermediate events from the association of causes or roots, which generated the top event. In it were identified the factors that cause fatigue as; manufacturing failures, machine misuse, design condition failures, and adverse conditions. The structuring and combining of the causes that will form the top event are carried out through logical operators used in Boolean algebra analysis, in logic gates of the type "E", "OR" etc (Siqueira, 2005; Dias et al., 2013).

The macrography test was carried out to determine if there was any change in the microstructure during the welding process. For this purpose, the region close to the weld was prepared in two steps, the first one by roughing, by means of a mechanical sander to be possible to obtain a flat surface and with the desired orientation, the second step, the polishing, was carried out with sands 220 and 320 to achieve the desired roughness.

The macrographic attack was performed by immersion, where the polished surface is immersed in a vat containing a certain volume of the reagent, as reagent used the iodine reagent, composed of 10g of sublimated iodine, 20g of potassium iodide and 100 ml of water, Figure 2. The elements was weighted using the precision balance Shimadzu AUY220. The iodine reagent was used to reveal local or partial changes of thermal origin. A heterogeneity was revealed by the macroscopic attack, the microscopy was performed in the place to analyze the microstructure, and determine which are the microconstituents present, since they vary according to the heat treatment suffered by the part in the welding process.

Figure 2. Elements of iodine reagent. Source: Authors.

To perform the micrograph, it is necessary to take a sample in the axis and for this a mechanical sander was used to remove the region of interest of the axis. During the whole operation, a thermographic camera was used to guarantee that there was no more than 100°C heating, excessive heating may be evidenced by the chemical attack, distorting the image interpretation.

All samples preparation procedures for metallographic analysis followed Rohde (2010). With the aid of saws, the region of interest that was divided in three parts was cut so that the metallographic analysis could be performed, the first part being the melted zone, the second the transition zone, and the third composed only by the base metal.

The samples were taken to the hot inlay with the Risitec 30 RS stuffer, with the use of bakelite for the preparation of the specimens, Figure 3. After the embossing, the specimens were sanded using smaller grit sizes (120,220,400, 600, 800, 1200) with the aid of Fortel model PLF polishing machine at a speed of 125 rpm. Then, the samples passed through the polishing process in which alumina paste of 1 µm and 0.3 µm was used. After the polishing, the chemical attack was performed so that it could visualize the different phases of the microstructure along of the thermally affected zone (ZTA), identifying its regions. One of the reagents indicated for steel according to Colpaert (2008) is Nital 2%. Its composition is 2% HNO_3 (nitric acid) and 98% ethanol. This was used for the chemical attack, by means of immersion, varying in times of 10, 15 and 20 seconds of immersion. Then, the specimens were taken to the Olympus BX51M microscope for visualization of the microstructure.

Figure 3. Micrograph test samples. Source: Authors.

After the metallographic analysis, the specimens were taken to the Rockwell hardness test using the hardness tester of the MSM (EXP) model of Importécnica, according to ISO standard 6508-1 (2005).

3. RESULTS AND DISCUSSION

In the figure below the FTA of the studied equipment is presented, it was verified during its study that faults such as; Poor surface finish, welding bites, presence of a thermally affected zone, presence of corrosion, presence of stress concentrators live corners, were detected and may have been fundamental for crack nucleation and propagation through the fatigue mechanism.

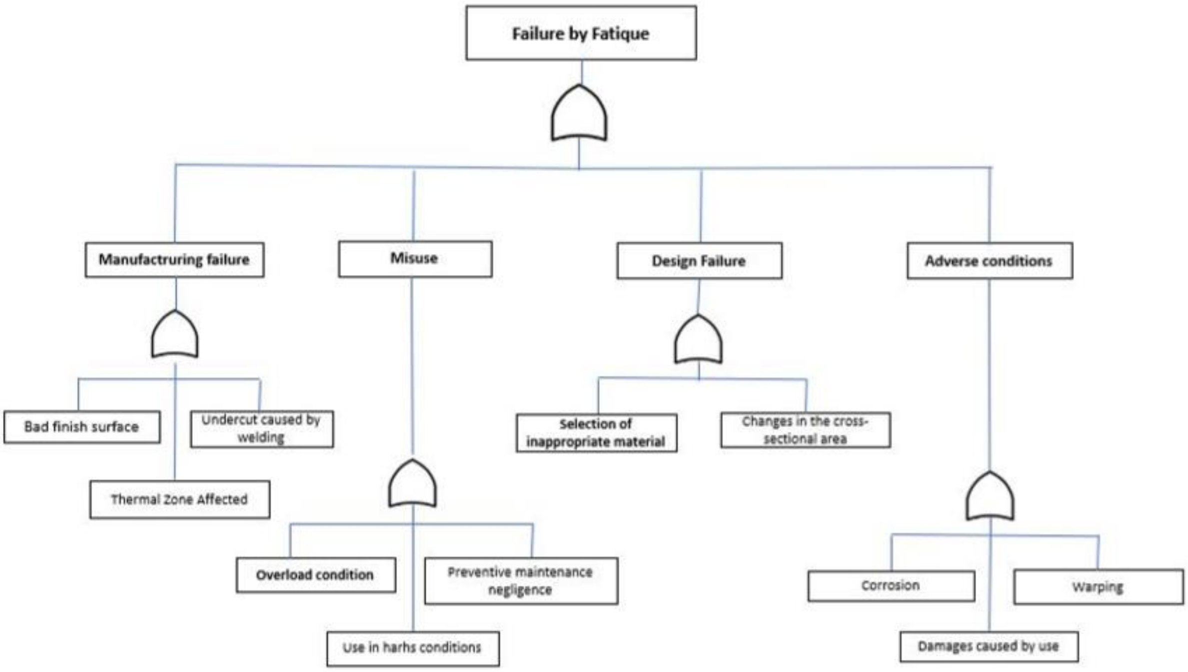


Figure 4. Fault tree analysis of truck shaft. Source: Authors.

When analyzing the axis in question it is noticeable that there was no care for the part to have a good surface finish, a crucial aspect for elements that are subject to cyclic stresses, since generally the maximum tension in a mechanical component is found on its surface. Therefore in most cases of mechanical failure by the fatigue mechanism, crack nucleation occurs on the surface of the component, poor surface finish can work as a voltage amplifier. Another stress concentrator that changes the life in fatigue is the presence of live corner in the axis when its section is reduced, in a good design the reduction of section would have the incorporation of a sweetening rounded so that there are no corners. The Figure 5 shows the fault region in the cross section of the axis, and the propagation of cracks, also called "beach markings", can be observed.

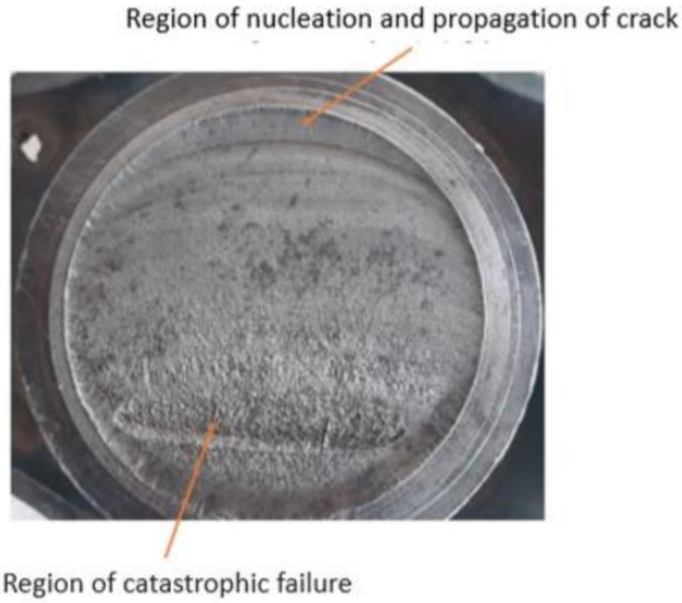


Figure 5. Surface of the fault. Source: Authors.

The axis studied has already undergone the process of welding which originated undercuts, common defect in the welding process, the causes of undercut could be, when the voltage is very high, if use the wrong electrode or if the angle of the electrode is wrong or high electrode speed is also one of the reasons for this defect. The figure bellow shows undercutting defect around the weld. Peres (2008) says that these types of notches cause a non-uniform distribution of the stresses along the part with a tension in the region near the notch larger than the average tension in the more distant regions, then acting as a tension lift or tension concentrator. If a gradient of tension is formed on the notch surface, this gradient plays a key role in the crack initiation process.

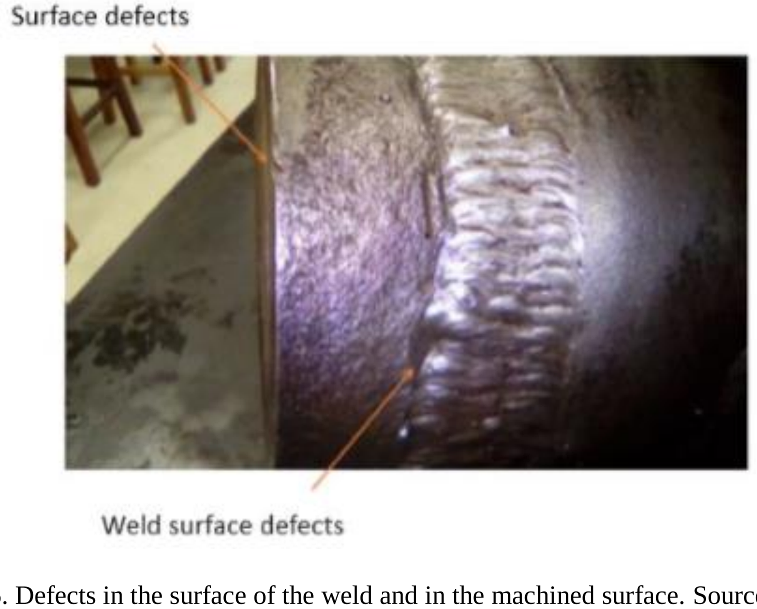


Figure 6. Defects in the surface of the weld and in the machined surface. Source: Authors.

In addition to surface defects, the welding process creates a heat affected zone (HAZ), a zone that had its micro-structure altered by the heat produced by the welding process, so the mechanical properties in this zone have been altered and may be a factor that facilitates nucleation of cracks. According to Gouveia (2013), welded structures have lower behavior than the base metal, because the welding process determines deep microstructural changes, making them harder and fragile, since the reduction in austenite content occurs, as well as the formation of defects, such as porosity and inclusions. In the figure below are dark spots that may be inclusions, future studies will be done and confirmed.

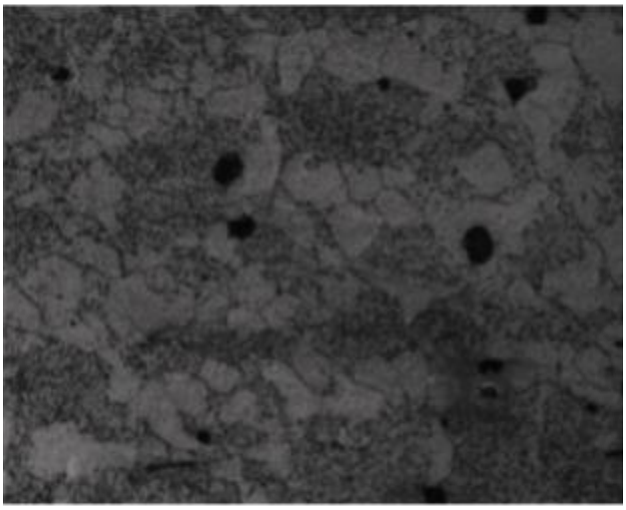
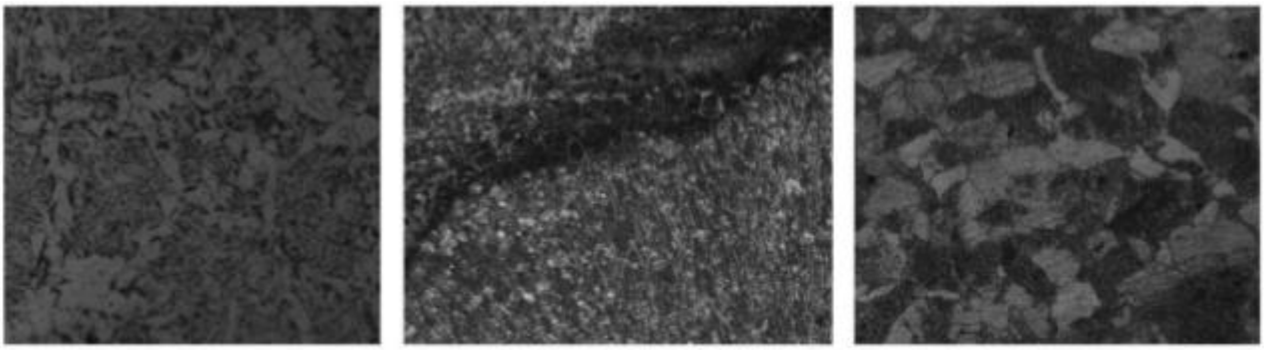


Figure 7. Micrograph showing inclusions from the welding process. Source: Authors.

The Figure 8 shows the images obtained in the micrograph of the three regions examined in the weld, with a magnification of 500x. Figure 8(a) shows the part of the melting zone constituted by the metal addition, it is observed grain boundary ferrite (proeutetoid), and inside the acicular ferrite grains, this result is in agreement with D'Avila et al. 2016. In 8(b) presents a zone affected by heat and constituted of base metal, grains transformed with ferrite proeutetoid and zone metastable with martensite and bainite. In this image, it is possible to observe these tree distinct regions of the thermally affected zone. Already in 8(c) represents the stable phases, ferrite and perlite observed in base metal.



(a) (b) (c)

Figure 8. Micrograph taken along the test piece. Source: Authors.

With the hardness test it was possible to quantify the hardness difference along the body by the change of microstructure, zone 8(a) had a hardness of 75 0.5 HRB, zone 8(b) 53 0.5 HRB and zone 8(c) with 45 0.5 HRB. Therefore, the weld function as a weak element of the element.

4. CONCLUSION

During the research were found several factors that are responsible for negatively influencing the fatigue resistance of the equipment studied. Among them we have the voltage concentrators being they reduction of cross section abruptly, presence of notches and undercutting originated by the process of welding. Also caused by the welding process we had incluses in the piece and also microstructural change in the welded place. The results of the hardness test confirmed the micrograph where it showed that the microstructure formed in the molten zone presented a higher hardness. As stated by Araldi and Bagetti (2016), such a difference between the mechanical properties of the base metal and the weld metal can cause a rise in tensions or deformations in the regions of lesser tenacity and to diminish the resistance to fatigue.

5. ACKNOWLEDGEMENTS

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