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Análisis de falla en propela de admisión en turbocargador de auto

Failure analysis of propeller shaft in automotive turbocharger

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Resumen

En este trabajo se presenta el análisis de la ruptura en la propela de un turbocargador Garret, tratando el tipo y características de fractura mediante la utilización de técnicas de caracterización estructural Difracción de Rayos X, Metalografía, Microscopia Electrónica de Barrido con Espectroscopia de Energía Dispersiva, Pruebas de Dureza y simulación CAD-CAE, la fractura en el material se observó con un microscopio electrónico de barrido, la medición de dureza ayudo a explicar la condición inicial de fractura, posteriormente con Difracción de Rayos X se logró observar la fase estructural del material ANSI 1045, además de correlacionar los resultados obtenidos por metalografía y resultados reportados de dureza, finalmente con el análisis de simulación mediante la teoría del método de elemento finito fue posible identificar y relacionar los espacios de concentración de esfuerzos con la falla mostrando congruencia y la relación con los huecos microscópicos en el material como se muestra en este trabajo.

Palabras Clave:
Cuerda cónica, Falla en material, Esfuerzo en propela de transmisión ANSI 1045, CAD-CAE, Caracterización de materiales.

Abstract

Rupture in propeller shaft in turbocharger Garret was analyzed, were tried type and characteristics of fracture, using Structural Characterization X-Ray Diffraction (XRD), Metallography, Scanning Electronic Microscopy (SEM) with Energy Dispersive Spectroscopy (EDS), Hardness Testing and simulation CAD-CAE, the fracture was observed on initial point with SEM, the hardness helped to try to explain the relation on initial fracture, XRD led know the structural phases to identify the original material ANSI 1045, supported with the values obtained in metallography and hardness reported in material detected, finally the analysis with Finite Element Method and the material proposed was possible identify the spaces with stress concentration, the results were demonstratives about of every factor analyzed on failure, showing an image with dimples in material.

Keywords:
Conical thread, Failure in material, Stress propeller shaft ANSI 1045, CAD-CAE, Materials Characterization.

1. Introduction

In mechanical machines there are failures on shells, on gears, supports, screws, bearings, shafts, the failures could be generated by vibrations, fatigue, corrosion, friction and wear properties of material, stress combined, and others causes (Altaf *et al.*, 2016. Ambadas, 2015) on occasions the parts are replaced on work time or cycles, but not always is possible determinate the time to change the mechanical element and have knowledge about of failure let identify causes that could be considered to avoid have problems in operation (Bedkowski *et al.*, 2014). Equipment widely used is the turbocharger and exist different failures, models, designs and mechanical studies, being possibly causes the materials used, work conditions, mechanical stress (Diesch *et al.*, 2020).

On recent years some transmission shafts are made of medium carbon steels (0.15-0.40 carbon percent such as 30C8), for greater strengths high carbon steels are used such. For applications where corrosion and high wear takes place, shaft material used is alloy steel using Ni, Cr, Mo ($16Mn_5Cr_4$, $40Cr_4Mo_6$) (Hariom et al., 2016). In case of alloy steels, it are well option due to the added advantages, but on price the commercial shafts are made of low carbon steels, usually are produced by hot rolling and finished to size by either cold drawing or turning and grinding. They are further hardened by oil-quenching to achieve the required strength and hardness, when are required very large sizes the billets are forged into the bars and finished by usual turning and grinding. (Rashid *et al.*, 2012). Design of shafts mainly depends on strength basis and torsional rigidity basis and still with the instructions during many years ago by traditional process, but with the Computer Aided Design ant the studies of materials on characterization is possible get different solutions with products of higher mechanical resistance using simulation and it help to customers to choose a different option with a serious study on problems and solve of the

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problems in machinery using design and characterization of materials, in this work were analyzed the failure and possible modifications on design (Velmurugan *et al.*, 2016)

2. Materials and methods

Propeller shaft in turbocharger Garret was analyzed on failure zone using JEOL scanning electron microscope at 15 kV to evaluate morphology of deformations and with EDS made possible identify elements, hardness on material was tester with Mitutoyo Wizhard Digital applying three measures on every area, XRD led to know structural phases in material of shaft propeller, on metallography were used sandpapers on 80, 120, 180, 220, 320, 400, 600, 800, 1000, 1500 on 15 minutes, using alcohol to polish and sulfuric acid to attack the material.
Computer Aided Design was applied to determinate the stress distribution and possible fracture toughness.

3. Results

On the failure in propeller shaft was observed the relief on surface with granular shape in Figure 1(a) and (b), the thickness of material shown the characteristics on ductile material as plastic deformation or reduced diameter and texture, in the figure was possible identified the fracture initiation zone with sudden rupture led identify the zone to be analyzed using SEM.

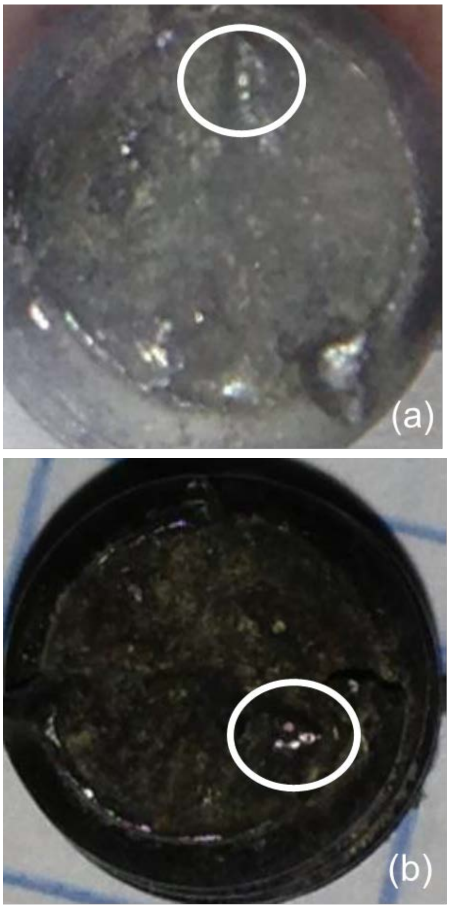


Figure 1: Failure on surface zone.

With Scanning Electronic Microscope was observed the propeller shaft of failure turbo compressor on thread root as reported M. Iphorski *et al. 2003* (Figure 2), they made failure analysis on rod vapor valve with failure located at the thread root. Iphorski identify that thread is a tensile concenter when there is high precipitation on grain borders and obviously is the fragile area.

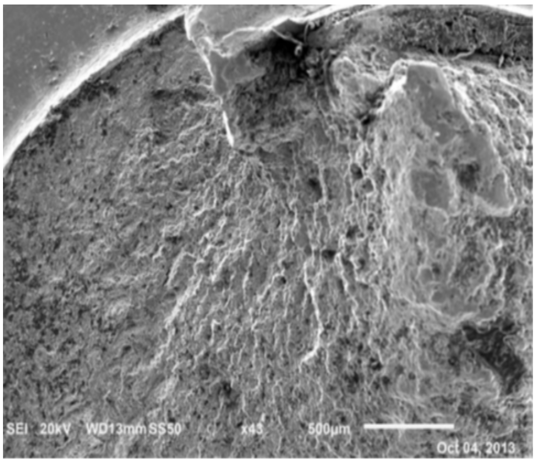


Figure 2: Initialization failure (J. Ovejero García *et al)*

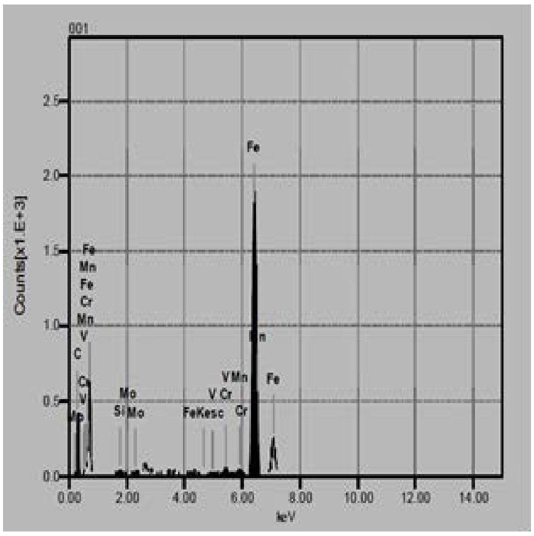


Figure 3: Elements detected in sample by EDS analysis.

With Energy Dispersive Spectroscopy were detected the elements V, Mn, Si, Mo, Fe and Cr in sample of propeller shaft as is showed in Figure 3.

In Figure 4 is shown the SEM micrograph of the fractured material, was possible identify dimple rupture as usually appear on ductile materials, like an inter-granular fracture was observed so that fracture is typical in fiber zones, being possible use materials different to avoid this type of fracture.

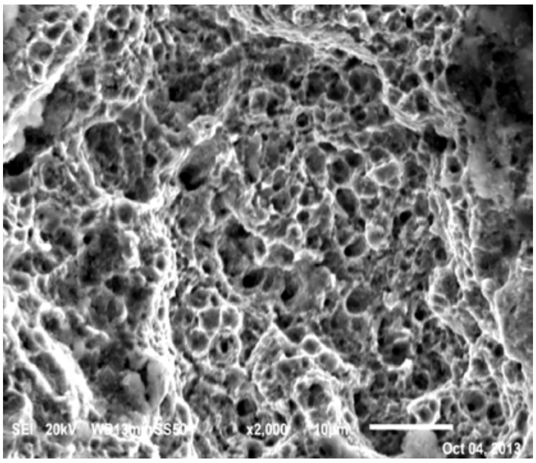


Figure 4: Surface with dimple rupture.

Respect to phases in material with metallography microscopy was determined with carbon, ferrite and perlite phases as is shown in Figure 5 and Figure 6, the phases are well defined, as is know the designers and companies avoid show specifications about of materials used, but with characterization techniques is possible compare the results to identify the material and generate possible recommendations in design to try to generate better results, so is possible compare the image of metallography with the phases identified on patrons of steel ANSI 1045. The hardness test let the evaluation of materials with the next values on HRC scale, the results indicate a similar ANSI 1045 steel (Principles of heat treatment of steel American Society of Metals), other situation was the maximum hardness detected in the center, it is a factor to generate the failure of material in the center of piece, as shown in Table 1.

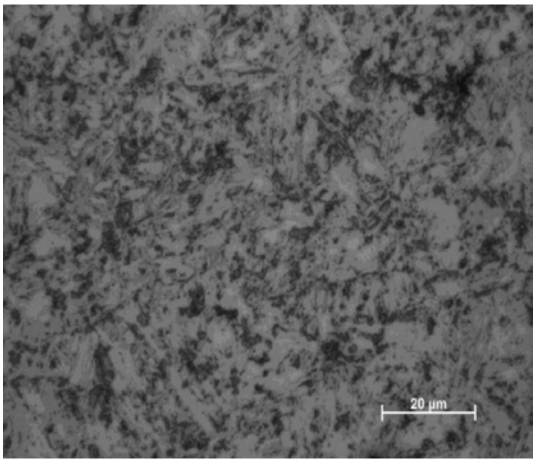


Figure 5: Surface with tearing

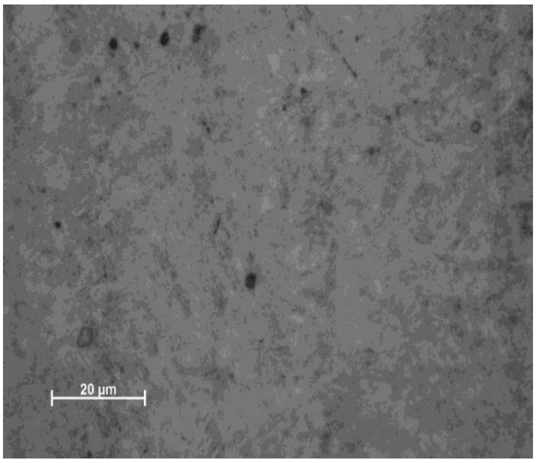


Figure 6: Ferrite and perlite phases in simple.

Table 1 Hardness in sample material

Test on sample	Value	Position
1	21.2	On center of piece
2	16.8	On extreme of piece

The analysis using CAD-CAE led analyzed the stress conditions on fragile section of propeller, it is only to compare possible areas, because the failure was not by stress, the analysis approximate to possible fracture toughness by simulation and try to understand the failure depending on loads, so were applied loads on the elements as is shown in Figure 7 on original conditions, on the figure 8 was possible identified sections to load an fix, so that on Figure 9 were showed the fixed elements to analysis, while on figure 10 are showed the values of loads on propeller, the moment correspond to motor. The results obtained on analysis in Figure 11 showed stress acceptable on mechanical resistance using steel ANSI 1045, the Von Misses stresses determined were under the values of resistance material, it is adequate with operational work, because the piece was working various years but is notable identify the spaces of stress concentrations on extreme, as can be observed in Figure 12, was possible identify concentration stress on thread root with this analysis, fibers observed, harness in the center and microvacancies facility the origin of fracture.

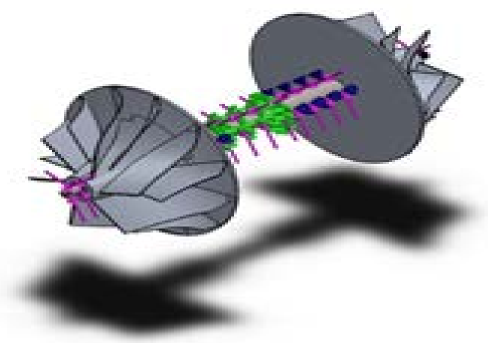


Figure 7: Original geometric conditions.

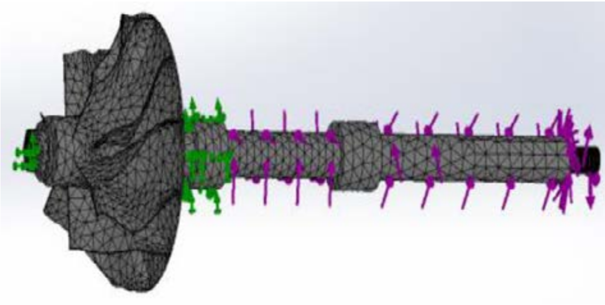
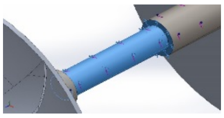


Figure 8: Loads and meshing to analysis.

Fix	Image	Details
Fix1		**Load:** **Fix geometry**

Reactions

Components	X	Y	Z	Result
Reaction (N)	**-1849**	**-788**	**-395**	**2048.11**

Figure 9: Image of condition to fix.

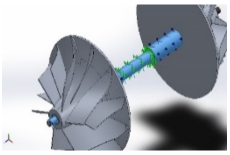
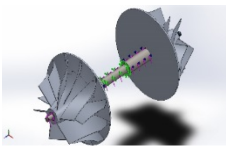
Load	Image	Load details
Torsion-1		**Load: Moment** **Value: 150 Nm**
Torsion-2		**Load: Moment** **Value: 150 N.m**

Figure 10: Image of loads.

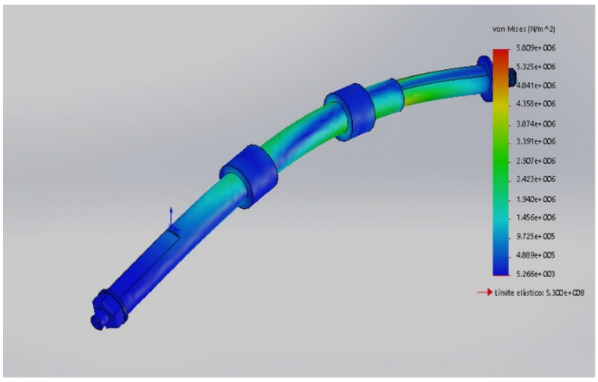


Figure 11: Stress distribution on propeller shaft

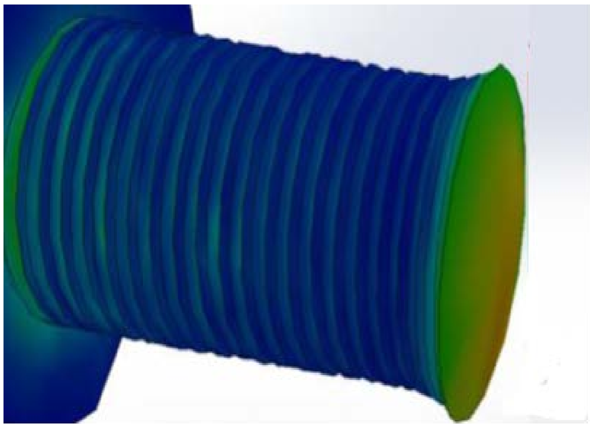


Figure 12: Maximum value on center of element stress.

In Figure 13 is observed yellow colors localized on thread root of propeller, with a value of approximately of 4.538 MPa, it value is adequate on design, but the colors help to identify the fracture section, is close to real failure. The result confirms the identification of concentration stress, which was like failure in the propeller shaft part.

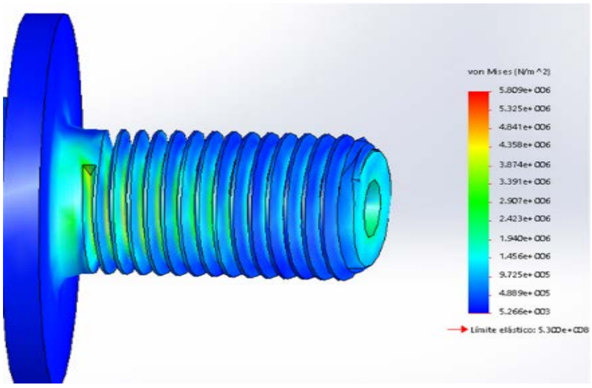


Figure 13: Maximum stress on thread root of propeller.

In the design made by software CAD-CAE, was modified the geometry. In this case the linear thread was modified to a conical thread, The Figure 14 present the difference in tension with a lower value under the same conditions of experimental set up. In the Figure 15 is presented an enlarged view of the modified conical thread section, additionally are show the values of maximum stress on propeller shaft.

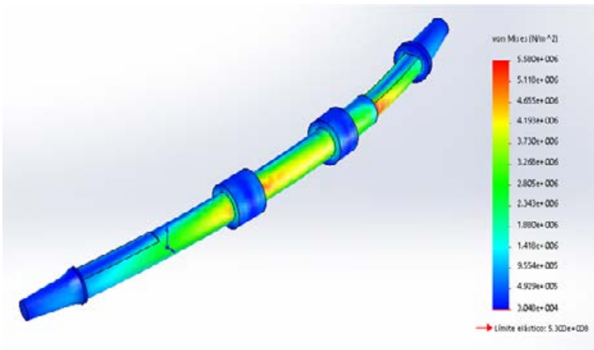


Figure 14: Maximum stress on propeller shaft.

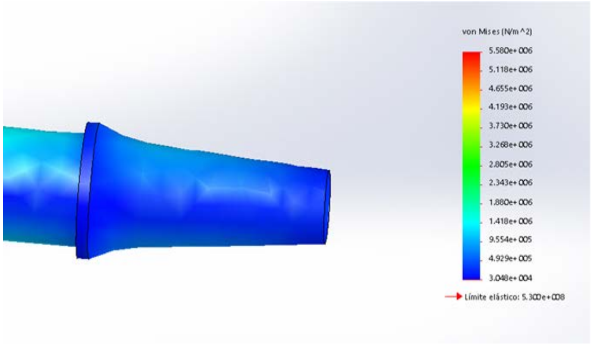


Figure 15: Maximum stress on modifies conical thread.

Finally, in XRD profile shown in Figure 16, obtained of propeller shaft sample, the peaks identified corresponding to a phase of ANSI 1045 steel like those reported by Eduardo da Rosa Vieira *et al*. 2021, all evidence allow identify the material close to ANSI 1045 which is considered for its properties and results from the simulation as the most appropriate material for support maximum stress on thread propeller.

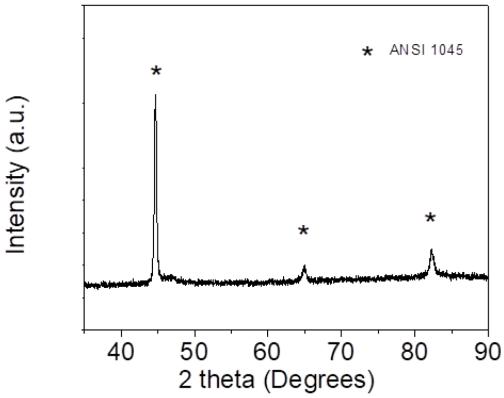


Figure 16: XRD profile of sample with failure.

Conflicts of interest: The authors declare no conflict of interest.

4. Conclusions

The study led identified factors as microvacancies, hardness in the center of piece, metallic phases formed, and spaces with concentration of stress that facilities the formation of fissure and cause failure on propeller shaft in turbocharger Garret, the techniques of characterization helped to identify the properties of material to closer the identify of material used in the piece, the study led know particular situations that could permit add elements to have better conditions on distribution of material with grain fine and change conditions and possible modifications on design to avoid stress conditions.

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