STRESS ANALYSIS AT THE CRITICAL POINTS OF A STABILIZER BAR

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ABSTRACT
The present work aims to analyze the fracture of a stabilizer bar of a passenger vehicle. The goal is to identify the structural stress on the bar and the region of fracture. The mechanical properties of the bar as the yield strength, the ultimate strength and elongation percentage was quantified using a universal testing machine. It was obtained the mechanical properties in tension and hardness of the bar material. The microstructure was characterized by optical microscopy. The observed microstructures were ferrite and pearlite. The steel used in the stabilizer bar has been classified by chemical analysis as SAE 1045. The analytical calculation of the stresses acting at critical points of the bar was performed to check the displacement range that the bar support without reaching the yield strength of the material. The strength criterion used for failure analysis was the maximum distortion energy (Von Mises), due to material work under cyclic torsion. By the Von Mises criterion, the stabilizer bar supports a stress of 503.4MPa for a displacement of 120mm. In the region of bar fracture, it was observed the propagation of radial cracks at the point of stress concentration towards the center of the bar. Analyzing structural stress, it is identified the need for improvement of the fatigue resistance for the material, since for displacement up to 120mm, the stresses calculated by the Von Mises failure criterion may cause the failure of the bar.

Key Words: Stabilizer bar, Stress, Displacement, Critical points, Vehicle.
1 - INTRODUCTION
An automotive suspension system is one that makes the connection between the car body and wheels designed to withstand the weight of the body and absorb the irregularities of the floor. This is an important component in the dynamics of the vehicle, providing comfort and safety to passengers. (Bosch, 1996; Bayrakceken, 2006).

There are several types of suspensions, however, this work will be restricted to McPherson model. This suspension setup has the advantage of requiring little transversal space, commonly used in front suspension of small vehicles. The McPherson suspension features are easy installation, fewer components and joints, low weight and little sensitivity to dimensional tolerance variations (Reimpell, 1996; Santos, 1999; Bosch, 1996).

A vehicle has good maneuverability when it responds promptly to commands from the pilot safely performing the evolutions in the various operating conditions. The dynamic behavior of a vehicle is the result of a series of parameters such as stiffness of the springs and dampers, the sizing of the stabilizer bars and regulation of aerodynamic appendages (Palma, 2002; He, 2010).

The stabilizer bar is one of the components of the suspension system that aims to contribute to the safety and dynamic stability of vehicles especially when traveling at high speeds and curvilinear trajectories. They can be manufactured of solid or tubular steel bars with the aim of reducing the angle of inclination of the body vehicle (Bosch, 1996).

Shafts suffer two types of damage: cracking and wear. The crash is caused by overloading or fatigue. The overload is the result of work done beyond the carrying capacity of the shaft, while fatigue is the loss of resistance exerted by the material of the shaft, due the demands over time. (Van Vlack, 1984; Beer, 1995; Cerit, 2010).

Steps and rebounds are usually used to provide a precise axial location of shafts, as well as to create an appropriate diameter to accommodate standard parts such as bearings. Wedges, retaining rings and pins are used for fastening elements attached to the axle in order to transmit the required torque. Each shaft section change contributes to the onset of stress concentration. Points with stress concentration should be considered in designing a mechanical component (Bonora, 1997; Hibbeler, 2000).

The aim of the present work is to calculate the stresses acting at critical points of a stabilizer bar of a passenger vehicle, to check the displacement range that the bar support without reaching the yield strength of the material. The strength criterion used for failure analysis was the maximum distortion energy (Von Mises), due to material work under cyclic torsion.

2 - METHODS

2.1 - Preliminary analysis of working conditions
Before starting the analysis of the failure of stabilizer bar, the bar working conditions has been analyzed. It is observed that the bar is subjected to thermal shock from the heat generated by the engine, the airflow incident and exposure to liquids of the track. Furthermore, the bar supports a load and a torsion caused by the suspension system. Figures 1 and 2 show the stabilizer bar studied here.
A chemical analysis was performed for classification of steel used in manufacturing the stabilizer bar. The mechanical properties of the material were quantified using a universal testing machine (tensile test). It was used one test sample to obtain the values of the yield strength and ultimate strength of the material. The metallographic characterization of microstructure and surface condition of the bar after the failure were evaluated in an optical microscope. The image was magnified 100x and 250x. It was performed a hardness test on 10 samples using a micro hardness (ABNT, 1996). It was calculated the stresses acting at critical point of a stabilizer bar, to check the displacement range that the bar support without reaching the yield strength of the material. The strength criterion used for failure analysis was the maximum distortion energy (Von Mises), due to material work under cyclic torsion.

2.2 - Criterion of maximum distortion energy (Von Mises)
This criterion suggests that the flow-through failure is associated with critical values of strain energy from the point under study. When the principal stresses have different values, the cube that represents the point turns to cobblestone (Hibbeler, 2000; Wulpi, 1999). The energy for this distortion is given by Eq. 1:

\[ U = \frac{1+\nu}{6*E} \left[ (\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2 \right] \]

(1)
where (E) is the elasticity modulus of the material and (ν) is the coefficient of Poison. The same occurs for the equivalent stress in this situation since σ1=σeq and σ2=σ3=0. For the equivalent stress, the distortion energy is (Eq. 2):

\[ U = \frac{1+\nu}{6*E} * 2 * \sigma_{eq}^2 \]  

(2)

Combining the Eq.1 and Eq.2:

\[ (\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2 = 2 * \sigma_{eq}^2 \]  

(3)

and:

\[ \sigma_{eq(VonMises)} = \sqrt{\frac{1}{2} \left[ (\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2 \right]} \]  

(4)

The criterion also considers the ductility of the material used and the yield strength and failure stress, and applied only for ductile materials (Souza, 1984; Bonora, 1997).

3 - RESULTS

The steel used in manufacturing the stabilizer bar has been classified by chemical analysis as SAE 1045, having 0.45% of carbon and 0.64% of manganese (ASM, 1995; ABNT, 1996). The material shows the presence of the elements listed in table 1.

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Ni</th>
<th>Co</th>
<th>Cu</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Percent</td>
<td>0.448</td>
<td>0.217</td>
<td>0.637</td>
<td>0.335</td>
<td>0.159</td>
<td>0.005</td>
<td>0.040</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Figure 3a presents a microscopic analysis of the bar (100X zoom), allowing to infer that the bar was not subjected to thermal treatments. Figure 3b presents a microscopic analysis of the bar (250X zoom), allowing to observe the presence of ferrite and pearlite.

Figure 3 – (a) Microscopic analysis of the bar (100X zoom); (b) Microscopic analysis of the bar (250X zoom).
The hardness test were performed on 15 samples taken from: (a) the fractured stabilizer bar; (b) an used stabilizer bar, but that did not suffer fracture; (c) a new stabilizer bar. Samples were taken diametrically in cross section and the values obtained are shown in Table 2, obtaining an average Rockwell hardness of 15 HRC.

**Table 2 - Rockwell hardness values obtained in tests.**

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Load</th>
<th>Minimum hardness</th>
<th>Maximum hardness</th>
<th>Average hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>150 kgf</td>
<td>15HRC</td>
<td>17HRC</td>
<td>15HRC</td>
</tr>
<tr>
<td>(b)</td>
<td>150 kgf</td>
<td>15HRC</td>
<td>17HRC</td>
<td>16HRC</td>
</tr>
<tr>
<td>(c)</td>
<td>150 kgf</td>
<td>15HRC</td>
<td>16HRC</td>
<td>15HRC</td>
</tr>
</tbody>
</table>

It was noted that the fracture occurred in the curvature radius immediately after the fixation point of the stabilizer bar. Moreover, it was observed that there is a notch enhancing the stress concentration in the failure region. This notch occurs on both sides of the bar, being result of the folding process used.

The values of the yield strength and the ultimate strength of the material were obtained in the tensile test (Table 3).

**Table 3 - Yield strength and the ultimate strength of the material obtained in the tensile test.**

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Yield strength (MPa)</th>
<th>Ultimate strength (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial 9.85</td>
<td>6.03</td>
<td>335.4</td>
<td>619</td>
</tr>
<tr>
<td>End 6.03</td>
<td></td>
<td></td>
<td>17</td>
</tr>
</tbody>
</table>

### 3.1 - Stress Analytical Calculation

The geometrical and mechanical properties of the stabilizer bar are shown below. (ABNT, 2002; Castro, 2010). For the material SAE 1045, the Elasticity modulus (E) is 205 GPa and the Coefficient of Poison (v) is 0.28. The elasticity modulus (G) and the moments of inertia (I) and (J) were calculated as follows:

\[
G = \frac{E}{2(1+v)} = \frac{205 \times 10^9 [Pa]}{2(1+0.28)} = 80 [GPa]
\]

\[
I = \frac{\pi d^4}{64} = \frac{\pi (0.01)^4}{64} = 4.91 \times 10^{-10} [m^4]
\]

\[
J = \frac{\pi (d/2)^4}{32} = \frac{\pi (0.01)^4}{32} = 9.28 \times 10^{-10} [m^4]
\]

The measured length of the bar, subjected to torsion is 0.88m. The diameter of the bar is 10mm. The geometry of the bar was shaped into a finite element software and the total flexibility of the bar was calculated equal 1.93x10^4 m/N (Cook, 2002). The presented calculation for the force F acting on the end of the bar was considered a displacement of 80 mm (± 40mm symmetrical):

\[
F = \frac{0.040 [m]}{f_{total}} = 207 [N]
\]

The flexion stress and torsion stress acting on the surface of the bar is:

\[
\sigma_{xx(flexão)} = \frac{F(l_1 + l_2)d}{l} = 91 [MPa]
\]
\[ \tau_{xy(\text{tor})} = \frac{F h (d)}{l} = 45 \text{[MPa]} \]  
(9)

and the principal stresses are:

\[ \sigma_2 - \sigma_{xx}^2 - \sigma_{xx} \tau_{xy}^2 = 0 \implies \sigma_2 = 0 \]  
(10)

\[ \sigma_{1,3} = \frac{\sigma_{xx}}{2} \pm \sqrt{\left(\frac{\sigma_{xx}}{2}\right)^2 + \tau_{xy}^2} \]  
(11)

This equation results in a stress \( \sigma_1 = 110 \text{[MPa]} \) and \( \sigma_3 = -19 \text{[MPa]} \).

Finally, the equivalent stress on the surface of the bar using the failure criterion of Von Mises (Hibbeler, 2000):

\[ \sigma_{\text{Al(VonMises)}} = \frac{1}{2} \left[ (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2 \right] = 151.0 \text{[MPa]} \]  
(12)

Table 4 summarizes the equivalent Von Mises stress and force \((F)\) to variations of the vertical displacements between \(\pm 20 \text{ mm} \pm 60 \text{ mm}\). This represents a vertical displacement ranging between 40 mm to 120 mm.

<table>
<thead>
<tr>
<th>Displacement (\pm (\text{mm}))</th>
<th>Equivalent Stress (\text{(Mpa)})</th>
<th>(F \text{[N]})</th>
<th>(\sigma_{xx} \text{[Mpa]})</th>
<th>(\tau_{xy} \text{[Mpa]})</th>
<th>(\sigma_1 \text{[Mpa]})</th>
<th>(\sigma_3 \text{[Mpa]})</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>323.5</td>
<td>443.6</td>
<td>195</td>
<td>97</td>
<td>235</td>
<td>-40</td>
</tr>
<tr>
<td>55</td>
<td>280.4</td>
<td>384.4</td>
<td>169</td>
<td>84</td>
<td>203</td>
<td>-35</td>
</tr>
<tr>
<td>50</td>
<td>237.2</td>
<td>325.3</td>
<td>143</td>
<td>71</td>
<td>172</td>
<td>-29</td>
</tr>
<tr>
<td>45</td>
<td>194.1</td>
<td>266.1</td>
<td>117</td>
<td>58</td>
<td>141</td>
<td>-24</td>
</tr>
<tr>
<td>40</td>
<td>151.0</td>
<td>207.0</td>
<td>91</td>
<td>45</td>
<td>110</td>
<td>-19</td>
</tr>
<tr>
<td>35</td>
<td>107.8</td>
<td>147.9</td>
<td>65</td>
<td>32</td>
<td>78</td>
<td>-13</td>
</tr>
<tr>
<td>30</td>
<td>86.3</td>
<td>118.3</td>
<td>52</td>
<td>26</td>
<td>63</td>
<td>-11</td>
</tr>
<tr>
<td>25</td>
<td>64.7</td>
<td>88.7</td>
<td>39</td>
<td>19</td>
<td>47</td>
<td>-8</td>
</tr>
<tr>
<td>20</td>
<td>43.1</td>
<td>59.1</td>
<td>26</td>
<td>13</td>
<td>31</td>
<td>-5</td>
</tr>
</tbody>
</table>

4 - CONCLUSIONS

The steel used in the stabilizer bar has been classified by chemical analysis as SAE 1045, having 0.45% carbon and 0.64% manganese. Analyzing the chemical composition of the bar and the work conditions, it is recommended the addition of alloying elements in the steel such as chromium, nickel and molybdenum to increase its strength.

The values obtained for the ultimate strength was 619 MPa. The literature shows the ultimate strength from steels SAE 1045 near from 580 MPa, which allows us to consider the values found reasonable. The elongation percentage of 17% is a value close to that found in the literature (18%) (Souza, 1984).

By the Von Mises criterion, the stabilizer bar supports a stress of 323.5 MPa for a displacement of 120mm. The yield strength obtained in the test was 335.4 MPa. The material (SAE 1045) presented adequate properties for use as a stabilizer bar. However, the properties of this steel can be improved with the implementation of thermal treatments.

In the region of bar fracture, it was observed the propagation of radial cracks at the point of stress concentration towards the center of the bar. Analyzing structural stress, it is identified the need for improvement of the fatigue resistance for the material, since for displacement up to 120mm, the stresses calculated by the Von Mises failure criterion may cause the failure of the bar.
ACKNOWLEDGEMENTS
The authors wish to acknowledge the Department of Mechanical Engineering of PUC-Minas, CAPES and FAPEMIG for the financial support.

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