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Failure analysis in aluminium turbocharger wheels

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ABSTRACT

This paper presents a failure analysis conducted in aluminium compressor wheels used in diesel turbocharged engines. These wheels were made with machined AA 2618T652 alloy and installed in light truck engines, which were used in rural and industrial atmospheres. The premature failures of the wheels happened after life between 40,000 km and 300,000 km, while the expected life was about 1,000,000 km. The present investigation showed that a fatigue process was triggered by intergranular corrosion on the upper camber surface of the wheel. A set of immersion corrosion tests was carried out to evaluate intergranular corrosion susceptibility of the alloy. The root-cause for the formation of the intergranular corrosion cracking in the compressor wheels could not be identified in the present investigation. The overall results indicated that an "in service" contamination of the compressor surface started the intergranular corrosion cracking, promoting the fatigue failure of the wheels.

1. Introduction

The turbocharger is basically an air pump, which makes the air/fuel mixture more combustible by introducing more air into the engine's chamber, creating more power and torque. Hot exhaust gases that leave the engine are routed directly to promote the rotation of the turbine wheel [1]. A typical diesel turbocharger rotates at speeds in the range of 100,000 rpm to 250,000 rpm. The rotation of the compressor wheel pulls in ambient air and compresses it before pumping it into the engine's chambers. The compressed air leaving the compressor wheel housing is hot as a result of compression and friction. Fig. 1 shows a cross section of a turbocharger and the location of the aluminium compressor wheel.

Light turbocharged diesel trucks presented failures of 51 compressor wheels in a total of 17,146 wheels. These wheels were made of AA2618 aluminium alloy, forged, heat treated (T652) and fully machined. This particular wheel presents 14 blades: 7 full blades and 7 small blades. The premature failures happened in light trucks running in rural and industrial atmospheres after life between 40,000 km and 300,000 km, while the expected life is about 1,000,000 km. The goals of this failure analysis were: to check whether the material of the failure wheels was in accordance with standards; and to identify the fracture mechanisms involved in the premature failure of the wheels. Nine compressor wheels samples were submitted to chemical analyses, microstructural characterization, X-ray diffraction, hardness testing and fractographic examination Table 1 presents the wheels identification, available vehicle mileage and failure location atmosphere.

The major stresses of rotating components are created by centrifugal forces and the highest tensile values are located at the bore, in the plane of maximum mass concentration at the largest diameter. A second relatively highly loaded region of wheels is the blade root which is connected to the backwall, near the outer diameter [2]. In service, the component is heated by the air compression and subjected to centrifugal forces imposed by angular speed. In a light turbocharged truck the compressor can be subjected to temperatures

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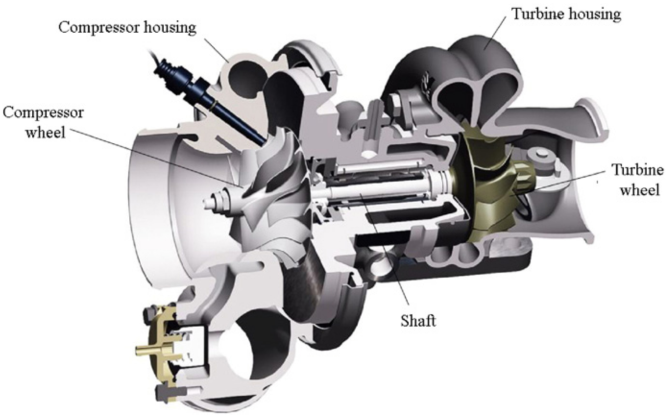

Fig. 1. Cross section of a turbocharger indicating the location of a compressor wheel.

up to 140 °C and to angular speed peak of 100,000 rpm. An estimation of tensile stress in the blade root imposed by the angular speed can be calculated by Eq. (1) [3].

$$\sigma = \int_{r_{root}}^{r_{tip}} \rho\, \omega^2 r\, dr = \frac{\rho\, \omega^2}{2}\left(r_{tip}^2 - r_{root}^2\right) \quad (1)$$

where:

σ is the tensile stress in the blade root [Pa];
ρ is the material density [kg/m^3];
ω is the angular speed [rad/s] and
r is the radius (tip or root) [m].

Considering the geometry of the failed aluminium compressor wheel with a density of $\rho = 2700$ kg/m^3, a root radius of 0.0125 m, a tip radius of 0030 m and the maximum angular speed (ω) of 100,000 rpm (10,472 rad/s), the maximum tensile stress in the blade root is 110 MPa. Since the cross section area is, generally, no greater than 500 mm^2, the load is equivalent to 5.6 tf hanging on each blade. To resist this load the selected aluminium alloy must be precipitation hardened to achieve the maximum yield and tensile strength. In addition, turbocharger manufacturers use a speed sensor to limit the overspeed and extend the fatigue lifetime. For even more critical commercial truck applications, Ti–6Al–4V alloy has been employed [2,4].

The aluminium alloy AA 2618 presents high creep resistance and has been used primarily as forgings, impellers and skin for the aircraft industry and compressor wheels and pistons to automotive applications [5]. The T652 temper applied in the alloy AA 2618 is equivalent to peak aged T61 temper and results in a tensile strength peak of 380 MPa, yield strength of 290 MPa [6]. The published mechanical property data of AA 2618 [6,7] shows that yield strength of T61 samples (exposed at 140 °C by 1000 h) is between 200 MPa and 220 MPa, the tensile strength is between 290 MPa and 310 MPa and the stress amplitude of fatigue endurance limit (room temperature, unnotched test pieces, LT direction and R = 0,05) is about 100 MPa [8].

The aluminium 2xxx alloys contain copper as the main alloying element. These alloys are precipitation hardened by a solution and artificial ageing heat treatments to increased strength via formation of coherent and semi-coherent Al_2CuMg (*S* phase) precipitates in the T6 and T8 tempers. These precipitates are initially anodic to the surrounding matrix. However, as a result of the copper-depleted-zones along the grain boundaries, they can become cooper rich and cathodic. In this case, a galvanic couple might be established, creating conditions for the formation of corrosion pits along the precipitate/matrix interfaces. The intergranular and stress corrosion

Table 1
Wheels identification and vehicle data for the failed compressor wheels.

Wheel #	Mileage [km]	Failure location (city–state)	Atmosphere
#2	39,080	Brasília — DF	Urban
#4	52.417	São Bernardo do Campo — SP	Industrial
#6	156,102	Formiga — MG	Rural
#21	152.193	Cláudio — MG	Rural
#22	68,226	Franca — SP	Rural
#31	204.949	Belo Horizonte — MG	Urban
#32	273.012	Brasília — DF	Urban
#33	62.294	São José do Rio Preto — SP	Rural
#51	266.292	São Bernardo do Campo — MG	Industrial