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Wear mechanisms of different engineering systems under higher solicitations: Overview and case studies

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ABSTRACT

Today's, vehicle systems and components require more interaction and innovation in mechanical systems. Furthermore, mechanical components should ensure by its properties the required functionalities. Potentially, under service, those systems are able to cause severe accidents. The particular attention is according to the improving requirements engineering in the choice of the material especially for automotive components submitted to higher stress level (induced by mechanical, thermal, tribological solicitations). Wear phenomena play a huge role in the effectiveness and durability of the vehicle system. The understand of wear as a failure mechanism induced by coupling and transient phenomena are fundamental in an innovative and creative process to improve automotive performance. Three cases of wear reported by the automotive industries are discussed in the text above: case 1: axle shaft of a motor vehicle, case 2: synchronizer rings, case 3: brake lining material.

1. Introduction

The service life of any component or device is established from the moment of its design to its manufacture. The safety of a vehicle has become a major preoccupation in the design, development, and validation of systems whose failures can have an unacceptable impact on the safety of personnel, equipment, and environment. Introducing safety considerations into the design and the fabrication of the systems entails a directly quantifiable economic cost, the resulting benefits are much less so, since the avoided incidents or accidents are not directly visible. To encourage fabricants to develop a voluntary approach oriented towards safety, it is essential to determine the failures linked to the highly solicited mechanical system: it consists of identifying and interpreting these clues to determine the root cause of the mechanical failure and take steps to prevent a recurrence. In fact, at the expense of the operating conditions that the vehicle components are often subjected to, they must operate without any form of inspection. Often, the failure of vehicle's components results in no more than a nuisance with the replacement of the part being required or in some cases majors they can cause an accident. Several failures are directly related to the driver, such as abusive use, accident and irregular maintenance of the vehicle which may negatively affect the performance of components that may not fulfill its role during operation. A previous study showed that the major component failures causes which cover the most critical cases are such as design, manufacturing, material etc. [1].

Furthermore, frequencies of causes of failure in some engineering components are reported as corrosion 29%, fatigue 25%, the

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brittle fracture 16%, overload 11%, high temperature corrosion 7%, stress corrosion 6%, creep 3%, wear 3% [2].

Referring to some research work, it has been shown that the physical wear's consequences may be manifested by [3].

(i) Ductile or brittle overload failure (cases 1).
(ii) Wear debris inducing contact problems (Case 2, 3).

In fact, wear consequences of material under torsional load is manifested by ductile/brittle overload failure. Studies that treat material's properties of the failed component aim to develop observational and reasoning skills for a better understanding of the interrelationship between failures and material's characteristic. It is, therefore, crucial to identify the most important causes of fatigue. A particular attention must be considered during design and manufacturing process of solicited components [4, 5], especially on the failure locations and types [6]. In addition, other investigations have been focused on the areas of stresses levels caused by torsional load [7]. Several research works investigate the effect of the material properties on torsion fatigue of shafts and confirm the interrelationship between material properties and its torsional fatigue performance [8, 9]. Moreover, not only material properties and design has an impact on the fatigue performance of vehicle components, but also an improper welding of hardened materials involves low ductility in the heat affected zones, high stress concentration and the appearance of inclusions in the structure inducing the propagation of fatigue cracks [10]. Otherwise, wear can not only be caused by overload failure but also it can be caused by the manifestation of excessive wear of two sliding components. In gearbox, the synchronization process is based on the generation of a friction torque between the conical surfaces before the gear is being sleeved positively engages by a positive locking for the transmission of the torque. In addition, a study which undertakes on the engagement of synchronizers in mechanical transmissions has shown that synchronization is conditioned by the drag torque and in the event of failure; it can even lead to the failure of the mechanism [11]. Some authors report the frictional responses of the contact between different components of the synchronizing system and the consideration of the lubrication which is variable from synchronization phase to another one [12, 13]. Few research works prove that the thickness of the lubricant affects the friction coefficient on the cone-shaped surfaces. Indeed, when the sleeve pushes forward the outer ring to move the clutch gear, the coefficient of friction on the cone surfaces increases suddenly whereas it decreases at the end of the synchronization process [14]. In fact, the friction coefficient depends on the material properties, temperature, and boundary lubrication. Besides, since the synchronization torque is expressed as a function of the coefficient of friction, to increase the synchronizer capacity, it is suitable to select the material which provides a high friction level, such as carbon fiber and brass [15]. As well as the coefficient of friction should be not higher enough to moderate the adhesive wear and consequently prevent the failure of the mechanisms [16]. Throughout the vehicle driving, thousands or even millions of gear changes are carried out. In each shifting, the synchronizer rings are responsible for the acceleration or the deceleration of the gears through their conical friction surfaces. The advanced study argues that to ensure a better performance of the synchronization system; the friction coefficient in those interfaces should be high and the wear should be as minimum as possible with the aim of ensuring a better the durability of synchronization system [17]. Nevertheless "friction" and "wear" are not always deleterious phenomena. When considering brake materials, the goal is to maximize friction with minimal wear. In fact, brake linings are important parts in vehicles, so their properties and behaviors must be well studied [18, 19]. However, this part is subjected to high levels of mechanical, tribological and thermal solicitations which can induce unexpected damage and lead to material's degradation [20, 22]. Various type of degradation can be involved such as crack, fracture and eventually wear phenomena [23, 25]. These phenomena result almost in material behaviors. In fact, many investigations were reported about the addition of different ingredients which differed in size and nature and how they affect the tribological performance of brake lining materials [26, 27]. Especially, material's properties such as physical, chemical, thermal and micro-structural which condition the failure of the brake lining eventually in terms of wear and friction. Several researchers prove that friction coefficient increase with the heat treatment of the brake lining materials even with the introduction or not of fiber in their formulation due to the grain growth and softening [28, 29]. These findings prove that braking performance depends on material's properties and it presents different treatments to improve its behavior via friction solicitation. Surface morphology plays also a significant role in the braking performance of the brake lining material, having a decisive influence on basic tribological properties as well as sealing conditions, fatigue limit, heat conductivity, friction, etc. [30]. The increasing of the temperature in the contact and the thermal stresses that occur during braking may cause undesirable effects on the material of the brake that probably lead to the initiation of the crack. In fact, the onset of degradation of friction material starts at 230 °C, and the degree of degradation increases with temperature within the range of 269–400 °C [31]. The predominant trend in the development of vehicles is focused on the increase of vehicle speeds, which increases considerably the energy required to be dissipated by the brake drum. On the other hand, the drum-lining interface temperature affects strongly the performance of braking. During severe braking solicitation, the temperature of the braking system increase rapidly and reach 650 °C and the overheating of the brake lining may cause serious problems, thus reducing safety [32]. The thermal shock and the localized heating may change the material's behavior due to metallurgical transformations, crack formations and residual stresses. Heavy heating in thin near-surface layers is responsible for thermal spots and micro-cracking sites that are observed on spots of the contact [33]. High temperatures of the drum brake lining cause probably fade and eventually lose effectiveness. The fade phenomenon is the result of too much heat build-up within the drum [34]. Hence, the drum brakes can only operate as long they can absorb heat generated by kinetic energy lost due to decelerating the wheels. Once brakes components are themselves become saturated with heat, they lose the ability to stop a vehicle. Besides, the frictional heat is not uniformly distributed on the rubbed surface of brake lining materials especially due to the thermal expansion and imperfections in geometry. In fact, it is well known that thermoelastic distortion due to frictional heating affects the contact pressure distribution and can lead to thermoelastic instability, where the contact load is concentrated in one or more small regions on the brake disk surface [35, 36]. These contact zones then can reach very high temperatures and the moving of these hot spots under