Tribology of wheels and tyres engineering essay

Tribology has been there since the beginning of recorded history. Tribology is the word basically derived from Greek in which tribos means rubbing. From this we understand that “ Tribology is the scientific study of interacting surfaces and of related subjects and practices”. The three factors that are considered to be a major factor in tribology are friction, wear and lubrication. Friction is defined as the opposite force created when two surfaces are in contact. Friction can cause damage to the parts in contacts due to the heat generation and this can be studied using tribology. Wear is defined as the irregularities caused in a surface due to the external factors. Running a machine with worn parts can reduce the life of the machine. Lubrication is defined as the viscous liquid, solid or gas applied between two surfaces in contact to reduce the friction and wear.

A wheel is a circular component that is intended to rotate on an axial bearing. They are mainly used in transport applications effectively as means to move an object from one place to another with the help of an external force. Wheels are widely used in conjunction with axles with any one of the components allowed to rotate. A wheel doesn’t stand by itself. They are constructed using the following parts.

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Figure 1 – A Wheel and Tyre on a BMW M3 Sedan

From the above figure, we can observe the following parts of a wheel

Rim- Outer circumference of the wheel, holding the tyre.

Hub – Centre of the wheel where the spokes meet.

Spokes- The rods which branch out from the hub connecting the hub with the rim.

Tyre – Circular shaped housing made of rubber covering the rim of the wheel.

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Figure 2 – A car tyre

The most important and fundamental part of a wheel is a tyre (as referred in UK). So the tyre keeps the wheel in contact with the ground whilst enabling smooth drive and better vehicle performance by absorbing the shocks and cushioning the vehicle. A tyre works as a wheel only after its fixed on a rim and inflated therefore the tyre-wheel assembly is crucial in the vehicle performance. It also allows for the motion the vehicle with a minimum frictional force and distributes vehicle weight over a substantial area of contact between the tyre and the road surface.

A tyre is also made of different components which are shown in the figure below.

Belts

Treadcontr

Body plies

Beads

Sidewall

Liner

Figure 3 – Parts of a Tyre

Beads are rings of steel wire in rubber at the inner edge of the tyre.

Body plies are made up of fabric and cords wrapped around the beads and extending over the inside of the tyre below the rubber surface.

Tread is the ridged surface that is in contact with road.

Sidewall is the part of the tyre from the beads to the tread.

Belts run around the tyre below the tread to strengthen both body plies and tread.

Liner is a thin layer of rubber bonded to the inner surface of the tyre.

Tribological Audit:

In analysing any tribological problem, a generic and systematic approach should be taken in determining tribological factors that may be important to the particular situation thus encouraging a problem centered approach. The figure below shows the major tribological factors that are considered.

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Figure 3- Classification of Tribological Factors

Materials used for making for making Wheels and Tyres:

Materials are selected from a tribological perspective as shown below. Let's see how the materials used have an impact on the overall tribological performance on wheels and tyres.

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Figure 4: Classification of Materials

Tyres are usually made using natural rubber or neoprene (synthetic rubber). Rubber is a unique material that is both elastic and viscous. Rubber parts can therefore function as shock and vibration isolators and/or as damper. Natural rubber is a product coagulated from the latex of the rubber tree, (hevea brasiliensis). Natural rubber features low compression set, high tensile strength, resilience, abrasion and tear resistance, good friction characteristics, excellent bonding capabilities to metal substrate, and good vibration dampening characteristics.

Wheels based on the use of light metals such as aluminium and magnesium has become popular in the market. This wheel rapidly becomes popular for the original equipment vehicle in Europe in 1960’s and for the replacement tire in United States in 1970’s. Aluminium is a metal with features of excellent lightness, thermal conductivity, corrosion resistance, characteristics of casting, low temperature, machine processing and recycling, etc. This metals main advantage is reduced weight, high accuracy and design choices of the wheel. This metal is useful for energy conservation because it is possible to re-cycle aluminium easily.

Magnesium is about 30% lighter than aluminium, and also, excellent as for size stability and impact resistance. However, its use is mainly restricted to racing, which needs the features of lightness and high strength at the expense of corrosion resistance and design choice, etc. compared with aluminium.

Wheels are widely manufactured using alloys of aluminium and magnesium. Since aluminium is the most widely used metal to manufacture wheels let us see the basic mechanical properties of rubber and aluminium listed in a table below. These properties influence the direct contact between the relative and absolute surfaces.

Mechanical Properties

Rubber

Aluminium

Elastic Modulus – E (109N/mm2)

0. 01-0. 1

69

Poisson's Ratio –

0. 5

0. 33

Yield Stress (MPa)

—

7-11

Hardness (durometer)

10-90

107

Ultimate tensile strength (mm2)

11

110

Thermal Conductivity (W/mK)

1. 59

75-235

Table 1. Basic Mechanical Properties of Rubber & Aluminium

Friction:

The friction between the tyres of an automobile and the road determine maximum acceleration and more importantly the minimum stopping distance. So the friction between two surfaces should be taken into consideration. In this case, rubber has a coefficient of friction of 0. 7 for dry roads and 0. 4 for wet roads. Under ideal conditions (no rain , dust particles on the road surface) the coefficient of sliding friction of about 5 will be obtained with a smooth tread since the adhesion is maximized by large contact are. If the road was wet, it would easily suppress the adhesion and produce very dangerous driving conditions and achieve very low coefficient of friction. Hence, the tread pattern on the surface of a tyre is to eliminate such drastic decrease in the coefficient of friction.

Tribology has made a significant contribution to the development of tyres. Friction between the tyre and the road surface is given by two components. The first part arises from atomic forces across the surface where the bonds between the tyre and road surface are broken in order to achieve sliding. As we saw earlier rubber has a very low elastic modulus which results in high frictional force giving good braking power.

Wear Resistance:

The issue of irregular tire wear has always been a concern even in the days when most vehicles ran bias ply tires. With today's longer wearing radial tires, irregular wear has surfaced as the primary concern of most vehicles maintenance managers. In fact, it is the ability of today's advanced radial tires to deliver long original tread life, which requires even more attention to good maintenance practices and vehicle alignment. Tyre wear is a complex phenomenon. It depends non-linearly on numerous parameters, like tire compound and design, vehicle type and usage, road conditions and road surface characteristics, environmental conditions (e. g., temperature) and many others. Yet, tire wear has many economic and ecological implications. The possibility to predict tyre wear is therefore of major importance to tyre manufacturers. Understanding of wear procedure could help to improve the quality of tires and other rubber parts working in heavy terrain conditions. In this project we need to sample a used tire (in our case, a bicycle tire) and try to find out which type of wear is dominating on the tyre. Let's look at the most common factors which influence wear is caused in a tyre

Scuffing: The most basic and dominant wear mechanism. It includes adhesive, abrasive as well as fatigue mechanisms due to cyclic nature of the loads.

Aggressive Driving: Hard cornering, spinning the tires when accelerating, and standing on the brakes can all wear tread off the tires very quickly. Changing your driving habits can extend tyre life significantly.

Underinflated Tyres: If the tires are not maintained at the recommended pressure and are underinflated, the tread flexes more than usual as the tyre rotates. Over many miles, this will increase tread wear.

All tyres have a tread wear rating, which helps users determine how long a tyre will last. A standard testing tyre has a rating of 100. This means that if a tire has a tread rating of 300, the manufacturer expects the tire to have a lifespan 300% of the test tyre.

Compatibility:

The final criteria when selecting a material is compatibility. This refers to the fact that some materials do not like being in proximity with each other or with a lubricant in between which can cause a whole range of problems such as wear. The chemical compatibility of rubber is very important because a rubber material can degrade quite quickly if it’s not compatible with the environmental conditions or the roads. Aging is recognized as deterioration in physical properties. Namely, aged rubber becomes either hardened or softened causing cracking or loss of adhesion or deterioration. The main causes of rubber aging in tires are Ozone, Heat and Deflection. To protect rubber from aging, Antioxidants and Waxes are generally used in the rubber compounding.

Surfaces:

The geometrical properties of the two surfaces are important to tribology in terms of their relative shape and surface texture as illustrated by the figure below

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Figure 5 – Surface factors

Conformity:

The degree of agreement between two surfaces is called conformity. It is important as it influences physical properties like temperature, pressure and shear stress. Wheels and tyres have low conformity and can be visualized of a ball rolling over a flat plate where the ball is the wheel and road as the surface.

Surface texture:

It is one of the most complex aspects of tribology. There are no simple design rules to follow when dealing with surface textures or conformity. Basically worn and unworn surfaces are compared and the amount of wear is analysed. Surfaces texture affects the degree of contact when they are in close proximity leading to wear.

Experimental work has revealed that there is a large variation in the degree of tire wear on different surfaces, the wear on the rough, harsh surface being approximately three times as severe as that on the rough polished surface. Qualitative analysis has shown that it is the harshness of the surface which is of major importance in tire wear, with surface roughness as a slightly modifying factor. Quantitative analysis of various parameters indicating surface characteristics has shown that the shape of the asperity tips and the low-speed, wet coefficient of friction are major factors. These can be used to predict wear to a high degree of significance within the range of values covered by these measurements, although a large sample of surfaces would be desirable to check this relationship further.

Lubricant:

Any substance used to reduce friction and wear and thereby to provide smooth running and satisfactory life of tribological components is called a lubricant. The most widely used lubricants are mineral oils, synthetic oils and grease. There are various lubricants used in different parts of the wheel. For example, the wheel bearings are lubricated with grease (can operate under high and low temperatures) and mineral oil is used for mounting and dismounting the tyres along the rim. Preferred materials for usage on beads of a tyre are:

1. Vegetable oil soaps

2. Animal soaps

These materials will have no adverse effect on tires or rims. If the approved lubricants are applied in water solutions, they must contain 10% to 20% solids and a rust inhibitor. When dry, the lubricant should have no residual lubricity and should not flake from the surface upon which it is applied. Lubricants are classified further on the basis of selection as shown below.

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Figure 6: Classification of lubricants

Viscosity:

An important property of any lubricant is the fluid viscosity. Viscosity is a measure of resistance to shear in a fluid or in other words the measurement of fluid's resistance to flow. Viscosity changes rapidly with temperature and pressure. Viscosity modifiers make oil's viscosity higher at elevated temperatures, improving its viscosity index (VI). This combats the tendency of the oil to become thin at high temperature. The advantage of using less viscous oil with a VI improver is that it will have improved low temperature fluidity as well as being viscous enough to lubricate at operating temperature. Most multi-grade oils have viscosity modifiers

Additives:

Additives are chemicals added to the mineral oils, synthetic oils and greases to make them perform specific functions like reduce friction, wear and maintaining cleanliness of the tribological interface. Additives comprise up to 5% by weight of some oil and there are different types of additives for different purposes.

Friction modifiers or friction reducers, like molybdenum disulfide, are used for increasing fuel economy by reducing friction between the tyres.

Extreme pressure agents bond to metal surfaces, keeping them from touching even at high pressure.

Antiwear additives or wear inhibiting additives cause a film to surround metal parts, helping to keep them separated like zinc dialkyldithiophosphate.

Contamination:

The performance of oil lubricants can be largely hindered due to contamination from various factors like

Dirt from the outside environment, i. e. roads and pollution

Other fluids in the system

Materials removed from surfaces by wear

Degradation:

Degradation of a component is one particular aspect tribologists seem to make improvements on. Degradation occurs primarily because of the chemical reactions that take place between the tyre compound and the road surface at high operating conditions which is reasonable. The process can be deterred by careful selection of lubricants which operate and high operating temperatures.

Operating conditions:

Unlike the preceding factors relating to materials, surfaces and lubricants, operating conditions are generally imposed by the function of the mechanism or system rather than being selected by the tribologist. The major operating conditions of a tribological system are classified in

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Figure 7 – Classification of Operating Conditions

Load:

Each tyre is designed to carry a specific load at a specific inflation pressure. Great care must be taken in determining the load applied to any tribological system as it has a major influence on friction and wear. Every tyre has a specific load rating which is important for our safety and our vehicle performance. Part of the tyre size is two digits that most of us are unaware of. The two digits before the speed rating symbol as show in the figure as 9 is the load rating. It determines the maximum amount of load the tyre is capable of holding and for different loads there are different load ratings. They can be found in vehicle’s handbook.

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Figure 9 – Load rating on a tyre

Relative Motion:

The relative motion you find in wheels take two forms, i. e. Rolling and Sliding. The wheels of a vehicle rotate around their axis and slide across the surface of the road. From this motion we can calculate the relative magnitude and is called slide-roll ratio. However it’s not only the magnitude of the motion that we need to consider but also the magnitude in terms of displacement, variation in time, velocity and acceleration. Higher operating speeds generate more friction and we need to be aware of wear characteristics.

Temperature:

Temperature of a system is measured to define the viscosity of the lubricant in particular. They are defined by combustion of engines, frictional heating in the brakes, etc. which are all external factors. Temperatures can have a damaging effect on the surface by affecting the performance of the lubricant both hot and cold. Tyre pressure varies significantly with temperature because air takes up more volume at higher temperatures and less volume at lower temperatures. As discussed earlier higher operating temperatures can manually degrade the tyre too.

Environment:

The nature of the environment surrounding any tribological interface is a major factor to consider. They have a major role to play in

Contamination of the lubricant (Grease, Oils)

Chemical reaction with the lubrication with can lead to wear

The tyres of a vehicle are subjected to the road surfaces and the climatic condition (dry and wet roads). Tribologists have no control over the environmental conditions but they can study the components interaction with the outside conditions and design them accordingly.

CRITICAL REVIEW OF THE DESIGN AND OPERATION OF TYRES

Frictional performance:

Various forces and moments that act around a tyre are necessary to outline an axis system for definition of frictional forces. One amongst the normally used axis systems governed by the Society of Automotive Engineers (SAE) is shown in Fig. The origin of the axis system is the centre of tyre contact. The X axis is that the intersection of the wheel plane and therefore the ground plane, with a positive direction forward. The Z axis is perpendicular to the bottom plane with a positive direction downward. The Y axis is below the ground plane, and its direction is chosen to form the axis system orthogonal and right.

There are three forces and three moments acting on the tire from the ground. Tractive force (or longitudinal force) Fx is the component in the X direction of the resultant force exerted on the tire by the road. Lateral force Fy is the component in the Y direction, and normal force Fz is the component in the Z direction. Overturning moment Mx is the moment about the X axis exerted on the tire by the road. Rolling resistance moment My is the moment about the Y axis, and aligning torque Mz is the moment about the Z axis.

_Pic5

Figure 10 – Frictional forces and moments on a wheel

The two important frictional forces that act on a tyre are the rolling resistance and traction. Rolling resistance is the force resisting the motion of the wheel when it rolls over a surface.

Friction between the tyre and the road is caused by sliding and the resistance due to the air circulating inside the tyre. Available experimental results give a breakdown of tire losses in the speed range 128-152 km/h (80-95 mph) as 90-95% due to internal hysteresis losses in the tire, 2-10% due to friction between the tire and the ground, and 1. 5-3. 5% due to air resistance.

The tyre carcass is the composite structure of the tyre in the manufacturing process, with the layers of rubber coated plies made of polyester, nylon, rayon, or steel, that comprises the resistant structure of the tyre upon which the tread, belts, bead, and sidewall are laid. When a tire is rolling, the carcase is deflected within the space of ground contact. As a results of tyre distortion, the conventional pressure within the leading half the contact patch is higher than that in the trailing half. The centre of traditional pressure is shifted within the direction of rolling. This shift produces a flash concerning the axis of rotation of the tyre that is that the rolling resistance moment. In a free-rolling tyre, the applied wheel torsion is zero; so, a horizontal force at the tyre-ground contact patch should exist to keep equilibrium. This resultant horizontal force is usually referred to as the rolling resistance.

_Pic6

Figure 11 – Variation of rolling resistance coefficient of radial-ply and bias-ply car tires with speed on a smooth, flat road surface under rated load and inflation pressure. (Automotive Handbook, 2nd edition, Robert Bosch GmbH, Germany.)

Surface conditions also affect the rolling resistance. On hard, smooth surfaces, the rolling resistance is considerably lower than that on a rough road. On wet surfaces, a higher rolling resistance than on dry surfaces is usually observed. Figure shows a comparison of the rolling resistance of passenger car tires over six road surfaces with different textures, ranging from polished concrete to coarse asphalt.

_Pic8

Figure 12: Variation of tire rolling resistance with pavement surface texture

Figure 12- Effect of Speed on the coefficient of friction between tyre and road surface

Wear behaviour:

Tyre wear is hard to predict and di¬ƒcult to understand. The tyre behaviour is e¬€ected by changing circumstances like: Routes and style of driving, road surface, season, the vehicle and the tyre itself. Wear in tyres are believed to be caused by the following reasons

The variation in wear rate due to driving style

The road surface characteristics (friction, abrasion)

Wear parameters depend on the season (Temperature and humidity)

The di¬€erent causes of wear lead to di¬€erent types of wear. They are further classified into regular and irregular wear (dynamic). Regular wear occurs on even spots along the tyre circumference or on the tyre itself making it easy to study wear.

Irregular wear on the tyre results in irregular spots on the tyre which wear faster than the other spots and it mostly occurs in undriven rear wheels. An example of irregular tyre wear is shown below.

Figure 13: Example of irregular tyre wear

Rubber wear:

Wear of rubber elements is understood to be a result of the energy evaporation because of friction. Friction of rubber materials can be divided into two main types, i. e. adhesion and hysteresis. The adhesion phenomenon is a molecular kinetic stick-slip situation between the rubber and the contacting surface. Hysteresis is a phenomenon within the sliding rubber.

Abrasive wear:

Adhesion occurs when two solid surfaces slide over each other under pressure. A temporary bonding appears between molecules of a sliding rubber surface and a contact surface due to the high pressure. The bonds are torn apart due to the continuing sliding, which results in abrasive wear. When both surfaces for instance have a perfectly smooth texture, like high hysteresis rubber on glass, both surfaces will be totally in contact. The resulting maximum possible contact area leads to a maximum adhesion force.

Figure 14: Schematic diagram of the friction and wear mechanisms in rubber

This is but not a typical scenario of adhesion for a road tyre. The sliding velocity is not high enough and each the tyre surface and particularly the road surface is too rough on a microscopic scale. Microscopic harsh textures, like asphalt, cause native adhesion by the roughness peaks of the materials that results in abrasion. The adhesion depends on texture properties, rubber properties and especially the vertical load and also the sliding rate.

Figure 15: Area of adhesion in different load situations

Figure shows the in¬, uence of the vertical load on the area of adhesion. Larger vertical loads squeeze the rubber material more between the irregularities of the road surface. This increases the overall contact area which results in more abrasion and adhesion.

Hysteresis wear:

At rough surfaces the tyre will wear because of deformation which results in fatigue. This is developed from the texture peaks as a result of viscoelastic behaviour leading to high deformation and rising slopes and low deformation at small slopes. Hysteresis is fairly subtle wear compared to abrasion but it’s continuous as the rubber slides over the slopes leading to pressure hysteresis in the rubber material as shown below.

Figure 16- Deformation forces which lead to hysteresis wear

Lubrication mechanisms and regimes

We saw earlier the types of lubricants generally used in tyres. The form of lubrication encountered in a tribological interface is a function of the

Materials of the surfaces

Surface conformity and texture

Lubricant properties

Operating conditions, such as load, speed, temperature and environment.

Lubrication regimes are a convenient and a powerful way of classifying the form of lubrication in the tribological interface. Let us see the different lubrication regimes that act on a tyre-road surface.

Lubricated friction in tyres is basically of two types, boundary layer lubrication and elastohydrodynamic lubrication. Boundary-layer lubrication occurs when the tyre and are in relative intimate asperity contact. A film of lubricant only a few molecular layers thick separate the asperities as shown below

Figure 17 – Boundary Layer lubrication

An elastic indentation of the rubber develops due to lubricant accumulation at the leading edge of the upper body. The inertia and viscosity-induced retardation of lubricant displacement account for the resulting indentation. This is called elastohydrodynamic lubrication and the accumulation generates an upward pressure which drastically reduces the friction force. The latter situation is hydrodynamic lubrication.

Figure 18- Elastohydrodynamic lubrication

A well known example of hydrodynamic lubrication is the aquaplaning of automobile tyres on wet roads. The water is dragged by the tire into the wedge shaped geometry formed between the tyre and the road surface, causing hydrodynamic pressure to build up at the front of the tyre. When the pressure is high enough to separate the tire from the road with a thin film of water, the tire loses almost all its grip and slippage is unaffected. To increase the speed at which aquaplaning might occur angled groove patterns effectively disperse the water from the contact patch.

Potential design changes to imrove Tribological performance:

There are many areas where the tribological researchers can look into in the designing of tyres. There is always scope for improvement in the advancement of technology.

Demand for increases service intervals- This demands the lubricant oil to perform for longer periods of time without degradation.

Better knowledge about the relationship between the solid particles and the wear of components can help in filtering the exact lubricant to be used.

Significant improvements are made in wear resistance, friction coefficients and load capacity by forming regular micro surface structure in the form of dimples using Laser Surface Texturing.