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ENGINE VALVE SEAT WEAR STUDY ON COMPRESSED NATURAL GAS (CNG)BY USING NANO POWDER

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ABSTRACT (120 words)

In automotive engineering, the research of alternative fuel is crucial to reduce dependency to the cost increasing for the use of gasoline. There is also need to find the best configuration of engine to match the alternative fuel. One of the current fuels capable to compete with gasoline in our country is Compressed Natural gas (CNG). This fuel is readily available in refilling stations nationwide and is used by Natural Gas Vehicle (NGV) on the road. Most of the engines use this fuel by retro-fitting existing engines with little or no modification to the existing gasoline engine. Hence, the performance of the engine using CNG is compromised. The purpose of the project is to find the mechanism that causes valve seat wear on CNG bi-fuel engines. A combination of CFD simulation for boundary input of experiment and experimental work will be used to determine valve wear rate. A fabrication of the stand alone valve tester enables precise work of measuring forces on a valve seat. A microscope picture will show the effect of valve wear rate. The significance of the project is to increase durability of bi-fuel CNG driven engines.

1. INTRODUCTION

Nowadays, the fuel and vehicles industries are dealing and struggle with hard international challenges due to rises technologies, administration rules. Despite the great strides forward that have been made in technology, failures continue to occur, often accompanied by great human and economic loss (Tung and McMillan, 2004).Engine valve train mechanism is the one of the important thing that need to investigate in the vehicles industries and combination of Camshaft, Roller tappet, Push rod, Rocker arm, valve and valve seat. The valve-seat contacts of internal combustion engines are subjected to combined attacks of impact and sliding under high temperature (Londhe, 2014).

This valve seat serves as seals for high-temperature, high-pressure & also does not adverse wear on valve, resulting in compression pressure and engine timing loss. Vehicle fuel and grease system need to make some improvise since rises of country administration rules needs to upgraded the engine fuel save and less emissions (Wang et al., 1996). Energy at high level influence the sustaining engine fuel and improve fuel-valuable vehicles will be more necessary in order to saving the natural assets and the reducing of engine problem. The study of other fuel is essential to lower reliance to the gasoline fuel rises cost time to time (Wang et al., 2012). Besides, researchers nowadays need to gain the best engine composition that match the improvised fuel. Recently, a lot of researches are travel around the world due to the purpose of improvised fuels and also conserve assets of energy that have so long been most general approaches in this field or industry. For example, biogass base fuel such as biodiesel and bioethanol no need engine adjustment to get best operation, but its set up various complication in the long term operation in term of the more percentage usage, that affect environmental shock and phenomenal threat to food resources (Jahirul et al., 2010).

One of the current fuels usable to give a challenge with gasoline fuel in our country is Compressed Natural gas (CNG) as it is readily available in oil refill stations nationwide and is used by Natural Gas Vehicle (NGV) on the road. Beside, the CNG has a less density but more octane number then gasoline fuel and cause it can work easily in a top compression ratio and more spontaneous ignition heat makes it a safer fuel in case of leakage than gasoline fuel(Bhattacharjee et al., 2010). A lot of the standard engines use this gases fuel by fitting back current engines with little or no customize to the current gasoline engine. Hence, the performance of the engine using CNG is compromised. The purpose of the project is to find the mechanism that causes valve seat wear on CNG lean burn engines due to increase the durability of the valve seat.

The valve-seat contacts of internal combustion engines are subjected to combined attacks of impact and sliding under high temperature (Londhe, 2014). In a car engine, exhaust valves are the ones most likely to burn because they run hotter than the intake ones. Exhaust valves, receive little cooling by the incoming air and fuel and are blasted by the hot combustion gases as they exit through the exhaust port which makes them much more vulnerable to wear than the intake valves. This valve is used to remove the burnt gases from combustion chamber to the environment. Opening angle and closing angle of exhaust valve having important role viewed from the point of performance and fuel consumption. Due to this opening and closing of valves should be optimum in order to get maximum power with less fuel consumption. Current CNG engines are mostly bi-fuel engines designed for Gasoline fuel. By using CNG fuel the valve is deprived of lubrication and hence reduce the valve durability. As that the material change in valve seat is again cost increasing & desirable up to certain limit. The analysis of valve wear is still at its infancy level and not much research was done on the matter. The difference wear effect on the gasoline and gasses fuel need to investigate with testing facilities so that a proper coating can be assessed.

2. RESEARCH METHODOLOGY

Experiment wear test

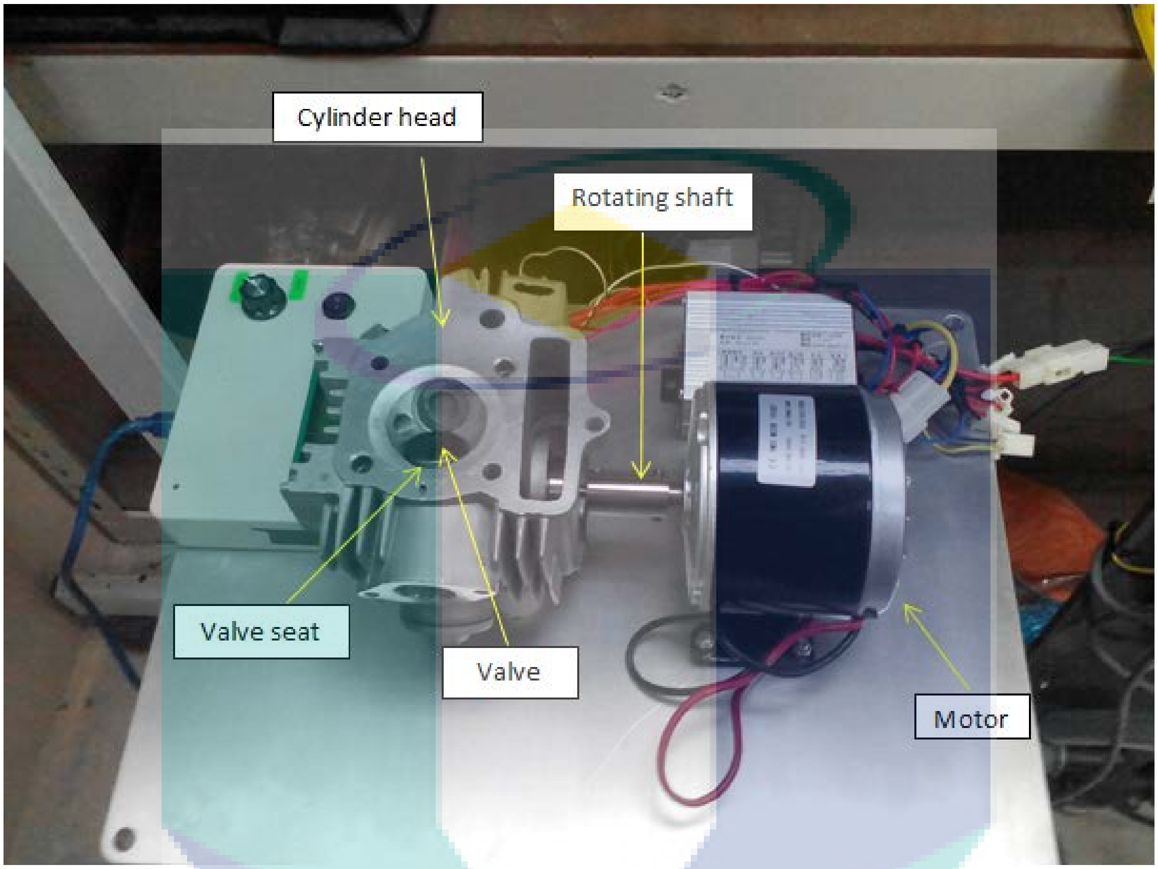


Figure 1: Simple valve train system

The motor act as the simulate to the simple valve train system. The rotating shaft connects the cylinder head and the motor. The valve used is poppet valve to ventilate the combustion chamber of an engine. The poppet valve has the advantage of opening perpendicularly to the sealing surface, which gives a minimum of relative motion. The valve seat is a round and ring shape and located below the valve seating face. As the motor start the rotating shaft will rotate the camshaft and the valve move up and down and give the pressure to the valve seat. Wear or recessions occur on the valve seat seating face as the cycle of the motor increase.

There are some variables involve in this project which are constant and manipulated variables. The constant variables are the engine cycle number, time (minutes), speed rate (rpm) and valve closing velocity (mm/s). The manipulated variable is the type of fuels. Table 1 show the details regarding the variables involve.

Table 1: Variables involve in the experiment

Variables	Values/ Types
Engine cycles number	2x10^4 cycles
Time (minutes)	15 minutes
Speed rate (rpm)	1200 rpm
Valve closing velocity(mm/s)	40mm/s
Type of fuel	CNG, Petrol

Wear Mechanism measurement

To define and investigate the wear mechanism, various instruments are available. The measurement method technique can be divided into two broad categories which are contact type in which during measurement a component of the measurement instrument actually contacts the surfaces to be measured and noncontact type. In this study, surface roughness tester (Marsurf PS 1, Perthometer) is used to measure surface roughness, Ra of valve seat seating faces as it is a contact type whereas optical measurement (Mahr Multisensor GmbH) is used to photograph the wear of the seating faces as it is a non-contact type.

Surface roughness (Perthometer)

Surface roughness often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. Roughness plays an important role in determining how a real object will interact with its environment.

This often results in a trade-off between the manufacturing cost of a component and its performance in application. As mention above, this project would use Perthometer to investigate the surface roughness as nowadays it is typical instrument for this specific purpose. Figure 2 shows the measurement locations of the Ra of the valve seat seating face. The Ra was measured at six points that were obtained by dividing the two seating faces in the direction of circumference at 45◦ intervals. The sampling length that set on the Perthometer was 1.75mm.

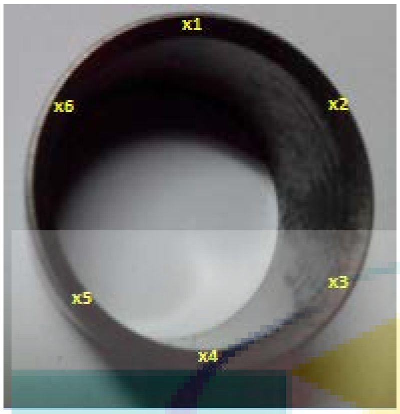


Figure 2 : Scanning Ra of valve seat at 6 six points

Optical Measurement (Light Optical Microscope)

Light optical images were photograph with a table top microscope. Higher magnification microscopy and surface analysis for determining the origin of wear particles. The magnify use on the Mahr Multisensor GmbH instrument was 4mm for the samples.

3. LITERATURE REVIEW

The literature review is about the mechanism of valve seat recession and how the method can overcome the valve seat wear in term off durability.

Tribology – friction, wear and tribofilm

In everyday life – all around us – surfaces are in contact and in relative motion against each other, whether we like it or not. The science dealing with all of this is referred to as Tribology and it is defined as 'The science and technology of interacting surfaces in relative motion', which includes all aspects of friction, wear and lubrication.

Friction arises when two surfaces are in contact under a relative motion. The surface asperities that come into contact during the motion results in a tangential force that counteract the motion. This force depends on numerous parameters, such as construction, contact geometry, lubrication, surface structure, material, sliding speed and temperature. This makes it difficult – and in many cases impossible – to predict its behavior with tabulated numbers in a textbook. It is important to remember that the friction is a result of all these parameters, and not a result of two mating materials. The unit of measurement is the coefficient of friction, μ, which is a ratio between the resisting tangential friction force, FF, and the applied normal load, FN.

Wear is defined as loss of material from a surface due to the tribological contact. It is often – but not always – an effect of a high friction force, as the large shearing forces developed by high friction may result in material transfer. As only a small amount of wear alters the performance of the valve system it is an important aspect in this thesis

Tribofilms is a collection name for phenomena that transform the original mating surfaces into new materials, with modified tribological properties. Often both the structure and composition are changed. Jacobson and Hogmark divide the tribofilm formation into two groups: Transformation Type Tribofilms and Deposition Type Tribofilms. The Transformation type includes the transformation of the original surface by plastic deformation, phase transformation, diffusion, etc. without any material transfer. The Deposition type films include the transfer of material from the mating surface, wear debris and/or the environment. Unlike many other critical components, the valve sealing interface is not efficiently lubricated. This is due to the high operating temperatures. Any friction reducing oil added onto the sealing surfaces would immediately vaporize since the surfaces are well above the boiling temperature of the oil. In the absence of an intentional lubricant film, we have shown that another surface protecting mechanism becomes important. Vaporized oil from the combustion chamber – together with deposits breaking loose from piston head and rings – will act as a source of particles that build up a smooth protecting tribofilm. This type of tribofilm, as exemplified in Figure 3, has proven essential for reducing the wear in the valve seat interface[1]. Combustion engines are used in many applications. The most common use is in the transportation sector where they propel the vast majority of the vehicles in the world. They operate by converting the expansion of hightemperature and high-pressure combustion gases into mechanical energy through displacement of a piston situated inside a cylinder. The piston is connected to a crank shaft that converts the displacement into rotational movement. During the induction and exhaust strokes the valves have to open quickly and be optimized for a high gas flow, see Figure 3. Wear on the sealing interface leads to a recession of the valve, which obstructs the through flow and hence decreases the effective output of the cylinder[1].

During the compression and power strokes the valves must efficiently seal the ports against the high pressures and temperatures that will reign inside the cylinder. If leakage occurs during these strokes, a large portion of the power is lost, which renders the cylinder useless.

The engine tribologist is required to achieve effective lubrication of all moving engine components. In order to reduce friction and wear, with a minimum adverse impact on the environment[2].

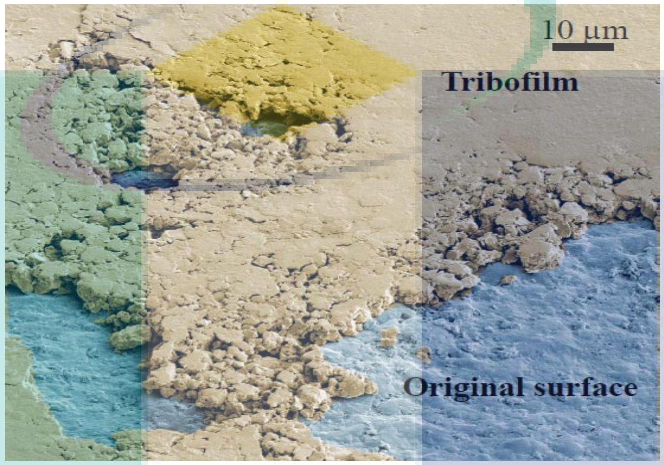


Figure 3 A smooth protective tribofilm built up from oil additive residue particles. From a valve sealing surface of a rig tested valve. Scanning ElectronMicroscopy (SEM).
Source : [1]

Valve and valve seat

The most commonly used valve type to ventilate the combustion chamber of an engine is the poppet valve. The poppet valve has the advantage of opening perpendicularly to the sealing surface, which gives a minimum of relative motion. In comparison to other sliding valve types, this reduces the
wear, reduces problematic maintenance and allows an easier adjustment for compensating wear

Valve and seat materials should have high strength, wear resistance, high temperature stability, and corrosion resistance[2]. In general, inlet valves are made from hardened low alloy martensitic steel for good wear resistance and strength. The exhaust valves are subjected to higher temperatures and are often made from precipitation-hardened, austenitic stainless steel for corrosion resistance and hot hardness. The valve seats are made from cast or sintered high carbon steel. In some high performance engines, the seat is formed by the induction hardening of the cylinder head material.

Both the valve and valve seat insert are exerted to high cyclic contact stresses and the high temperatures generated by the combustion as in Figure 4. Moreover, when ventilating, their surfaces come into contact with the hot exhaust gases and particles[1].

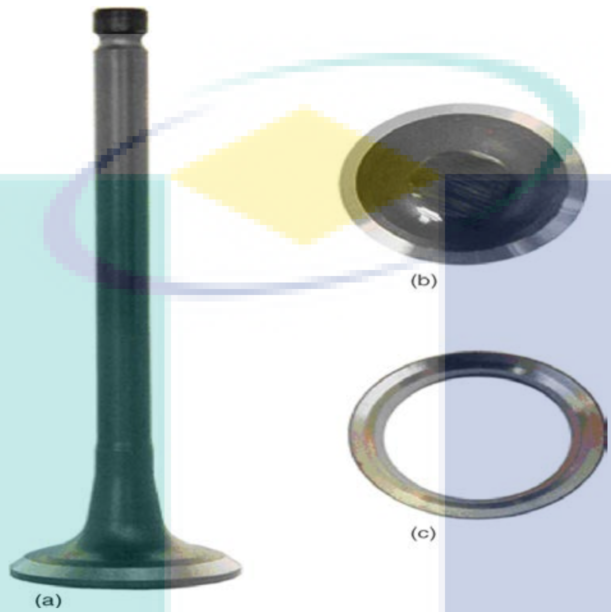


Figure 4: Valve and seat insert. (a) Valve (front); (b) valve (top); (c) seat insert.

Source : [3]

Exhaust valve seat

By default the highest valve is nearly 12% of engine cylinder bores. Inlet valve closes 20-40 ° after lower dead center and disclosed is usually about 10-20 ° before peak dead center . Commonly the exhaust valve have lower than intake the for some ideas For example while the suction stroke, the piston moves to the bottom, and the fuel-air mixture get in the cylinder barrel at a less motion. The exhaust gases escape the cylinder barrel with a maximum pressure during the piston moves to the peak when the exhaust stroke, the exhaust gases escape the cylinder barrel with a maximum pressure. So very large velocity exhaust gases escape the cylinder barrel. As a result, the inlet valve is bigger than the exhaust valve. In addition different with energy that only can only change form, but neither made nor terminated. All X get in intake valve as in Figure 5.

Nearly all of the energy used to push the piston down whenever time switched on. The residual energy (exhaust gases) is released the exhaust valve. Here only change it to heat but not making energy by flare up the mixture. There is less energy that has to escape the exhaust valve compared to what get in since piston pushed to the bottom used nearly all energy, there is less that has to go out the exhaust valve contrast to what came in. The total of the energy get in can never be less the energy to push the piston down and the waste that has to go out. Due to large amount of heat in the space of valve and valve seats, the specimen used lose its features of durability and can usually cause the valve and valve seats wear if its continues open and close[4].

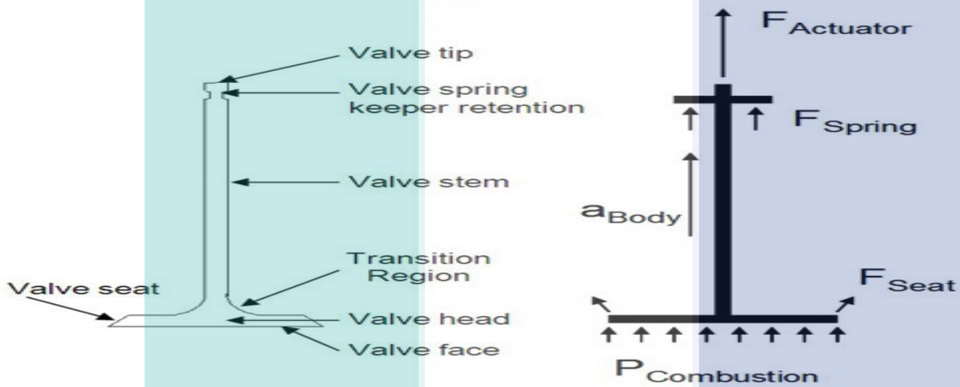


Figure 5: Valve details

Source: [4]

CNG fuelled engine

The scarcity of petroleum fuel resources and turmoil in the oil market along with the acutely growing demand of oil threatens the security of energy production. The necessity of fuel has gained the ground for adaptation of suitable energy policy for the transportation sector in order to balance the demand and supply of oil and to contain the overall release of the greenhouse gases with the eventual undesirable environmental impacts.

The drive created by the energy security, climate change and the rapidly growing demand of transport fuel lead to a quest for clean burning fuel. Recently, many people use Compressed Natural Gas (CNG) since it has many advantages to users. CNG is lighter than air, and mixtures of air and natural gas are inflammable only in a fairly narrow range of gas concentrations between 3.7% and 17% by volume. It is also an environmentally clean, plentiful, low-cost fuel for motor vehicles. Chemically, it normally consists of over 90% methane with smaller amounts of ethane, propane, butane, carbon dioxide and other trace gases. The high methane content gives natural gas its high ‘

octane rating (120–130) and clean-burning characteristics, allowing high engine efficiency and low emissions so that it can operate at a compression ratio of 11:1, greater than gasoline fueled engines. Besides, it has a lower adiabatic lame temperature (approx. 2240 K) than gasoline (approx. 2310 K) due to higher product water content. The CNG also conduct under lean burn engine that also have some advantages[5].

Since combustion under lean burn conditions leads to improved fuel efficiency, there has been a great deal of interest in lean burn technology for natural gas engines. A lean mixture has a higher resistance to knock than a stoichiometric mixture, and thus allows higher compression ratios to be used. A natural gas engine with a high compression ratio can attain high thermal efficiency due to low combustion temperatures and low throttling losses. As a gas, CNG requires a different approach of fuel induction mechanism at all normal temperatures and pressures. This has resulted in an increased interest in the use of CNG as fuel for the internal combustion engines and hence CNG has now been used to power vehicles of various ranges, starting from light delivery trucks to full size urban buses and other varieties of applications. Generally, the valve seat wear is more for gases engine that gasoline engine because of gases engine do not have liquid form that act as lubricant to reduce heat due to high combustion pressure without any lubricant[6].

Wear mechanism

Wear of the sealing surfaces is unwanted for several reasons. Investigations carried out shown that the valve and seat insert wear problem involves two distinct mechanisms:

Impact as the valve strikes the seat on closure.

Micro-sliding at the valve/seat interface caused by elastic deformation of the valve head and engine block as it is pressed into the seat by the combustion pressure.

Impact on valve closure causes plastic deformation of the seating surface, which leads to the formation of a series of ridges and valleys circumferentially around the axis of the valve seating face. It also leads to surface cracking and subsequent material loss from seat inserts at high closing velocities. Sliding causes the formation of radial scratches on the valve seat seating faces[1] in Figure 6.

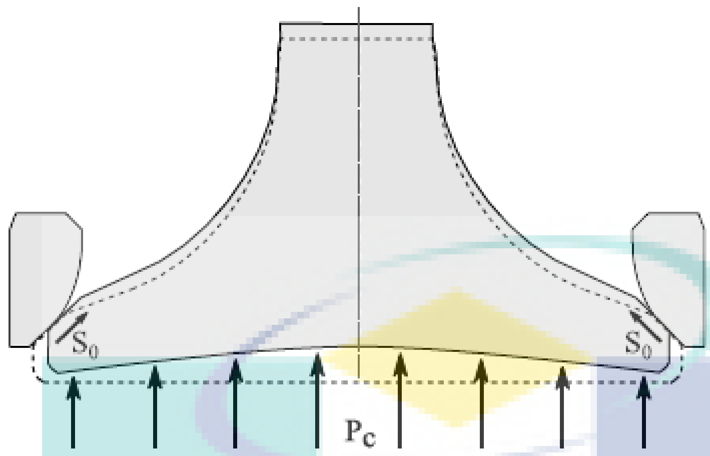


Figure 6: Deformation of the valve disc due to the combustion pressure, P_c, displaces the sealing surfaces relative to each other, yielding a small sliding motion, S_0, which give rise to sliding wear. Source: [1]

Increasing the combustion loading caused a greater amount of sliding at the valve and valve seat interface. Significant sliding can also occur if the valve is misaligned to the valve seat insert. Raising the valve closing velocity caused an increase in impact wear. Surface cracking and subsequent material loss was prevalent on valve seats and greater plastic deformation on the valve seating faces was observed. Recession was found to be approximately proportional to the square of the closing velocity (i.e. the valve kinetic energy on closing). Misalignment of the valve caused the valve wear scar widths at the point of contact to increase significantly, leading to increased sliding and hence greater wear[7].

Typically, the recession is lean on the characteristics of valve and valve seat specimen, amount of exhaust heat, angle between valve and valve seat, coating materials, combustion pressure, temperature and number of cycle. Wear is also persistent problem at the valve seat interface; the valve 'recesses' into the seat and results in loss of engine timing and compression pressure. The wear mechanisms of valves are not easy to investigate. They have been described to include a combination of abrasive, adhesive and oxidative wear[8].

Abrasive wear

Abrasive wear is usually observed by gouging and scoring on the contact surfaces, During engine operation, relative sliding of the mating surfaces enhances abrasive wear, In addition, hard carbides, trapped wear debris, combustion products, contaminant partides from oil, fuel and air are also influencing factors. At the onset of wear, the hard asperities or particles penetrate into the softer surface under the normal contact pressure. When a tangential motion is imposed, the materials in the softer surface is removed by combined effects of 'micro-plugging', 'micro-cutting' and 'micro-cracking'. As a result, the worn surface is generally characterized by grooves and scratches as an example shown in Figure 7. The wear debris often has a form of micro-cutting chips[8].

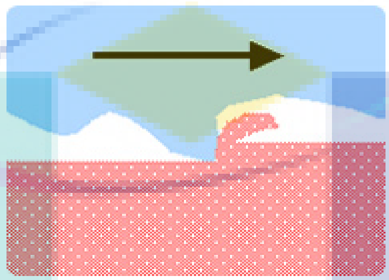


Figure 7 : Schematic of abrasive wear process

Source : [8]

Oxidation wear

Metal surface is normally covered with a layer of oxide, which could prevent metal-to-metal contact, and thus avoiding the formation of adhesion and reducing the tendency of adhesive wear. In this connection, oxide is a favourable factor in reducing wear rate of metallic materials. However, whether such beneficial effect can be realised or not is strongly dependent on the material properties and on contact conditions[8].

When the hardness of the metal underlying an oxide layer is low, or when the contact load is relatively higher, the metal beneath the oxide layer will plastically deformed, and asperities in the hard surface will penetrate through the thin oxide layer, leading to the normal metal-to-metal contact. In such case, wear by abrasion or adhesion will occur depending on the mechanical properties and chemical properties of the contacting metals. The beneficial effect of oxide is minimal and wear rate is generally high. On the other hand, when the underlying metal is hard enough to support the oxide film, such as on a surface engineered hard surface, a process known as oxidation wear will occur.

The mechanism of oxidation wear is schematically shown in Figure 8. At the beginning of a wear process, the original oxide film on the metal surface was removed when hard asperities rub across the high point of the oxide layer, leaving the underlying metal uncovered. The fresh metal will quickly react with oxygen in air to form a fresh oxide layer, which will then be scraped off again by asperities in the following cycle. Such an "oxidation - scrape", or "chemical - mechanical" cycle repeats during the oxidation wear process, producing wear debris of finely powdered oxide..

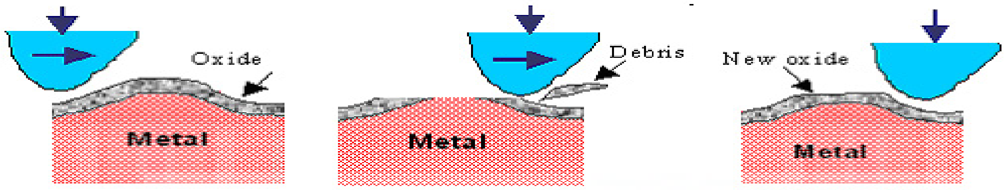


Figure 8 : Schematic of oxidation wear process

Source : [8]

Adhesive wear

Adhesive wear is characterized as micro-welding or bonding between contact surfaces. The contact surface projections or asperities are plastically deformed and eventually welded together by high local pressure. High contact stress, poor scat lubrication relative sliding and incompatible seat materials are thought to be the primary causes of adhesive wear. Some material combi nations under certain critical combinations of high stress or poor lubrication are prone to microwelding and breakage, leading to severe adhesive wear

Engineering surface is never perfectly flat. The surface of a most highly polished engineering component show irregularities or asperities. When two such surfaces are brought into contact, the real contact actually occurs only at some high asperities which is a small fraction, e.g. 1/100 of the apparent contacting area. As a result, plastic deformation and intermetallic adhesion will occur, forming cold weld junctions between the contacting asperities. The strength of junction is determined by the surface structure and by the mutual solubility of two contact metals. The tendency of adhesion is the lowest for a pair of metals with almost zero mutual solubility, but this is limited to very few metals. Most metallic materials show appreciable tendency of adhesion.

When two contact surfaces undergo relative movement, tearing must take place either at the (cold weld) junction or inside the original materials depending on which is weaker. If the strength of the adhesion junction is relatively low, as in the case of a contact pairs with low mutual solubility, or metallic surfaces separated by oxide film, tearing will take place at the junction and material loss during wear will be minimal. However, when tearing occurs inside the softer material, a fragment of the softer material will be dragged away and adhering to the harder body, as a schematic shown in Figure 9. This process is known as material transfer.

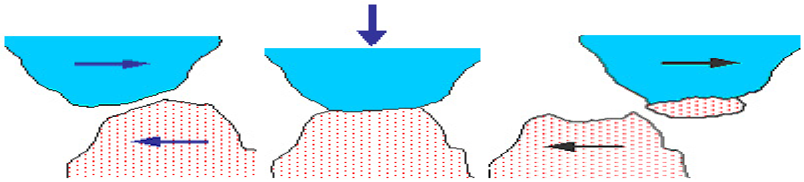


Figure 9: Adhesive wear occurs by material transfer

Source : [8]

Variables influence to wear

Valve and valve seat configuration

General in any engine valve & valve seat angle is 45°. In first test, the valve & valve seat angle is 45°. After getting the problem of valve & valve seat wear the angle change to 30°. Due to which the seat resting area is increased & the wear resistance is also increased. Following figure 10 shown the exact idea about the same[4].

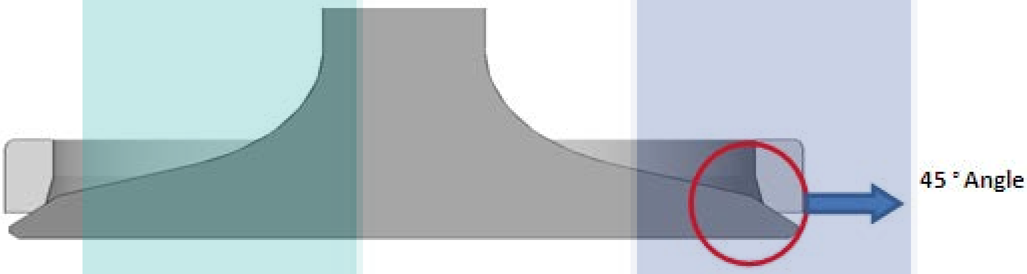


Figure 10: Valve & Valve Seat Angle (45°)

Source: [4]

As shown in fig. the valve and valve seat angle is 45°. When we compare this fig. with 30° valve & valve seat angle it clearly indicated that, the seat resting face for valve on valve seat is more in 30° angle. So that it can sustain more pressure i.e. load of combustion pressure. Due to increase in sustain load of combustion pressure, the wear resistance properties for valve and valve seat is increased. In this figure 11 the angle is 30°, so the seat resting area is more as previously discussed[4]

Figure 11 : Valve & Valve Seat Angle (30°)

Source : [4]

Temperature

The valve-seat contacts of internal combustion engines are subjected to combined attacks of impact and sliding under high temperature. There are mainly two factors that must be considered to analyse the effect of the temperature; on the one hand there are a reduction of the mechanical resistance with the increasing of the temperature, on the other hand increasing the temperature stabilizes the oxide surface layer enhancing its action as protective layer against the metal adhesion. The protective action of the oxides layer should lead to a reduction of the friction. However, in both the developed tribometer, as in the real valve-seat contact, the stroke of the sliding depends on the value of the friction force; a reduction of the friction will increase the sliding amplitude raising the abrasion wear, which is in good agreement with the obtained results and explain whymore severe regimes increase the valve recession[9].

At room temperature with a sliding speed of 0.1 m s^{-1}, the rings showed accelerated wear rates. However, except for this condition, wear rates tended to increase with increasing slidingspeed at room temperature. At 200 ^{o}C, softening had an effect on wear. At sliding speeds over 0.4 m s^{-1}, bright worn surfaces were observed, and wear rates increased noticeably. The maximum wear volume occurred at this temperature. In contrast, at 400 ^{o}C, oxidation had a strong effect on wear. Oxidized worn surfaces and no acceleration of wear rates were observed at any sliding speed. These results can be explained by the occurrence of oxidation and oxide film forms on worn surfaces,it can act as a general lubricant to obstruct metal to metal contact, thereby reducing wear [10].

Cycles number

The cycle number and Hz (RPM) are influence to the average Ra. The Ra refers to the difference between the maximum and minimum values of the measurement length. The Ra by dividing the two seating faces in the direction of circumference at 45◦ intervals. The Hz (RPM) change means the change in the valve closing velocity, which is known to have great influence on the wear of the seating face. It was observed that the base metal of the valve and seat insert seating faces beneath the tribochemical reaction product was damaged. This signifies that wear occurred due to direct contact between the base metals of the valve and seat insert before the tribochemical reaction product was formed and that it covers the contact area. The tribochemical reaction product has the effect of a wear protective layer. It can be seen that the tribochemical reaction product covers the valve and seat insert seating faces. Since the level of the surface of the tribochemical reaction product is higher than that of the seating surfaces of the two base metals, the tribochemical reaction products contact with each other first before the two base metals of the mating specimen contact. The tribochemical reaction product, being accumulated on the seating face, increases the average Ra and causes uneven contact when the valve is closed. This might worst the gas tightness of the cylinder.[11] as in Figure 12 and 13.

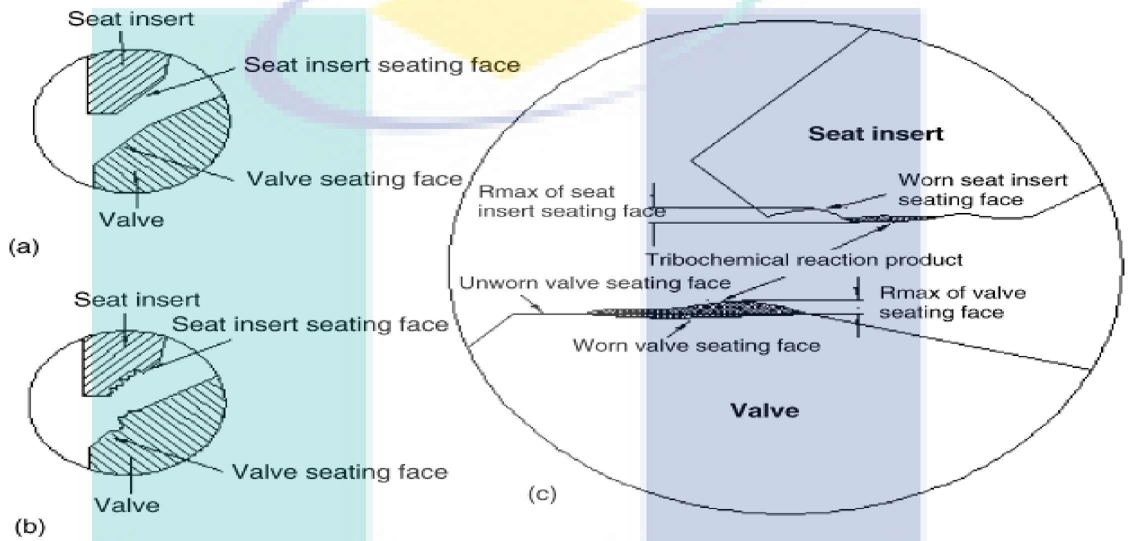


Figure 12: Definition of Ra. (a) Before experiment; (b) after experiment; (c) Ra concept of valve and seat insert seating face. Source : [3]

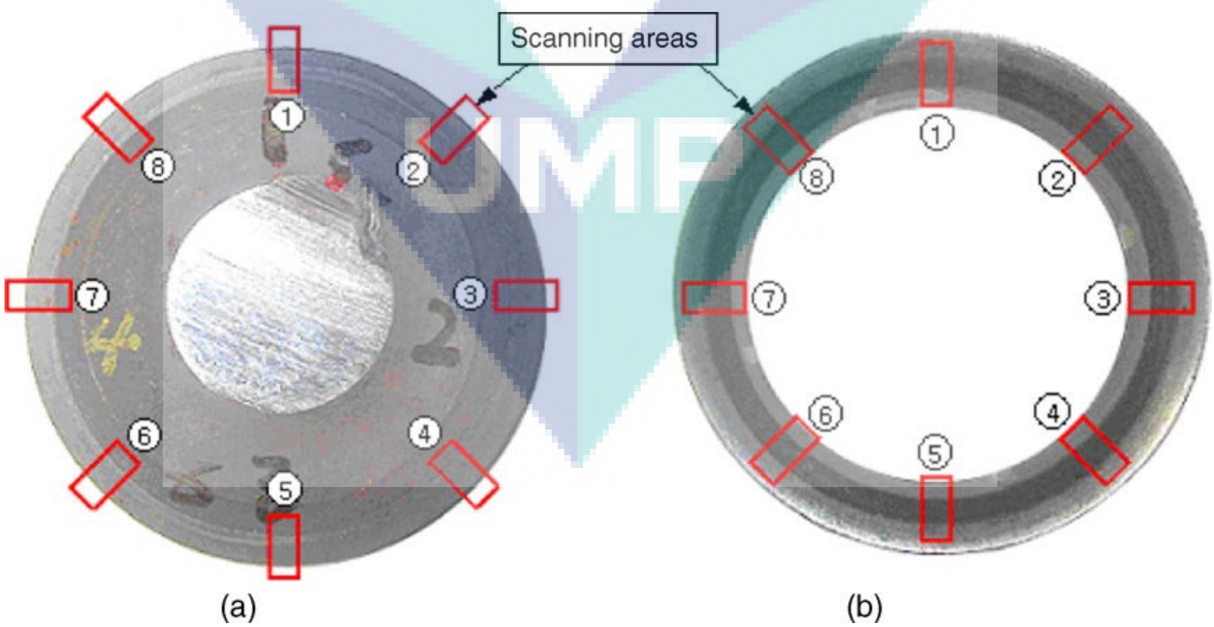


Figure 13: Scanning areas of valve and valve seat. (a) Valve; (b) valve seat.

Source : [3]

Wear measurement

The current standard engine should withstand 1,600,000 km without changing the valve or valve seat insert. The life time will of course vary between different applications. Assuming a 1,600,000 km service life at 60 km/h and 1,300 rpm average and knowing that the valve opens and closes once every second revolution. The number of cycles each valve has to endure is approximately 1,000,000,000. Consider that the maximum total wear allowed for the valve and valve seat insert together is 1.5 mm and that the wear typically is divided into 2/3 on the valve seat insert and the rest on the valve seat insert. This means that the net wear rate of the valve seat insert must be less than 0.01 Å per cycle. One atomic layer per 200 cycles, and half of that on the valve

If we assume that all of the wear is a result of the sliding wear and that the wear is linear, the specific wear rates for both materials can be calculated according to Eq.1

$$k_i = \frac{V_i}{FS} \quad \text{Eq. 1}$$

specific wear rate for material i, V – wear volume, F – Normal load and S – sliding distance

A distinction is made between methods of evaluating the nanoscale to atomic scale and microscale features of surface roughness. The researches require fine-scale details of surfaces and details of molecular roughness. These details are usually provided using methods such as low-energy electron diffraction, molecular-beam methods, field-emission and field-ion microscopy. Furthermore, most engineering and manufacturing surfaces, microscopic method suffice and they generally mechanical or optical methods and some of these methods can also be measure geometrical parameters of surfaces. Various instruments are available for wear measurement. The measurement method technique can be divided into two broad categories which are contact type in which during measurement a component of the measurement instrument actually contacts the surfaces to be measured and noncontact type.

Surface Roughness

Surface

A surface is a boundary that separates an object from another object or substance. In order to make understand the measurement of surface finish, surfaces can then further be divided into two more types. Real surface is one of the type which It is the actual boundary of an object. It is produced because of the process that created the surface.

Next, measured surface which a measured surface is a representation of the real surface obtained with some measuring instrument. This distinction is made, because no measurement will give the exact real surface as in Figure 14.

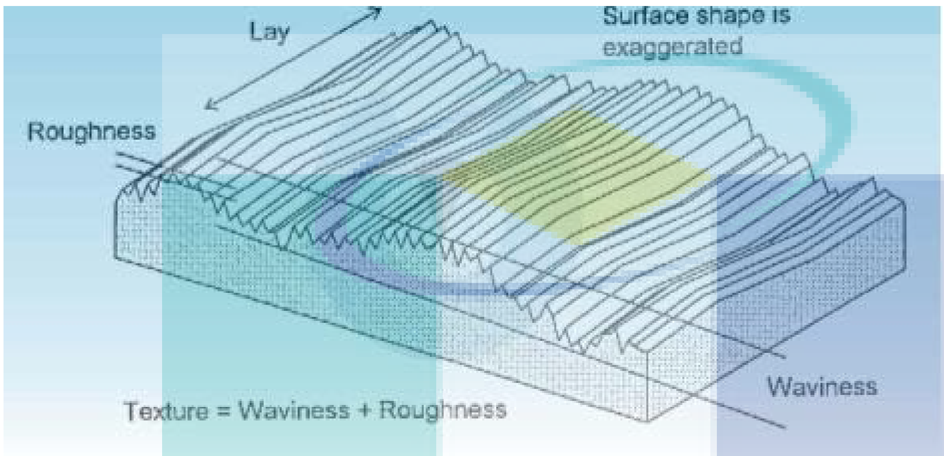


Figure 14: Magnified view of a sample surface and the characteristics of a surface.

Surface is made of – Roughness, Waviness and Lay.

In Figure 14 shows magnified view and characteristics. The definition of the term as following below:

-Surface Texture

Surface texture is the combination of fairly short wavelength deviations of a surface from the nominal surface. Texture includes roughness, waviness and a lay, that is, all of the deviations that are shorter in wavelength than form error deviations.

-Roughness

Roughness includes the finest (shortest wavelength) irregularities of a surface. Roughness generally results from a particular production process or material condition.

-Waviness

Waviness includes the more widely spaced (longer wavelength) deviations of a surface from its nominal shape. Waviness errors are intermediate in wavelength between roughness and form error. Note, that distraction between waviness and form error is not always made in practice and it is not always clear how to make it.

-Lay

Lay refers to the predominant direction of the surface texture. Ordinarily, lay is determined by the particular production method and geometry used.

However, in practice, both the words Surface Texture and Surface Roughness are used to explain common meaning of surface roughness symbols. Surface roughness heights are generally measured in micro inches or micrometers. A micrometer, abbreviated μ, is one millionth of a meter.

Interpreting thro average roughness indication

The most common and popular method amongst all is interpreting thro average roughness indication as in Figure 15. This is known as Ra – in which, R stands for Roughness and a stands for average. The other methods are Rz, Rt, Rmax etc. Below is the list of popular parameters:

Parameter	Name
Ra	Roughness Average (Ra)
Rq	Root Mean Square (RMS) Roughness
Rt	Maximum Height of the Profile
Rv, Rm	Maximum Profile Valley Depth
Rp	Maximum Profile Peak Height
Rpm	Average Maximum Profile Peak Height
Rz	Average Maximum Height of the Profile
Rmax	Maximum Roughness Depth
Rc	Mean Height of Profile Irregularities
Rz(iso)	Roughness Height
Ry	Maximum Height of the Profile

Figure 15 : List of roughness parameters

Ra – Average Roughness

The average roughness is the area between the roughness profile and its mean line, or the integral of the absolute value of the roughness profile height over the evaluation length. The formula used that relate with Ra is stated in equation below.

$$R_a = 1/L \int_{x=0}^{x=L} |h_i| \, dx \text{ , where L is sampling length} \qquad \text{Eq. 2}$$

Besides, the average roughness is by far the most commonly used parameter in surface finish measurement. The earliest analog roughness measuring instruments measured only Ra by drawing a stylus continuously back and forth over a surface and integrating (finding the average) electronically. It is fairly easy to take the absolute value of a signal and to integrate a signal using only analog electronics.

Surface roughness symbol is given to convey manufacturing process related information only. Unless written specifically on the symbol, they do not carry the surface texture type (i.e. plated / milled / cold drawn). These symbols are given irrespective of material and its surface condition. The latest Indian Standard for method of indicating surface texture on technical drawings suggests the practice of giving the surface roughness value directly in micron as Ra value or by grade numbers. The earlier method of indicating surface roughness through triangle symbols is now superseded, however still many companies are following the older practice. Below is the comparison table for all 3 ways of indicating surface roughness symbol in the drawing as in Figure 16.

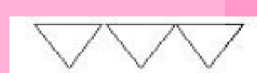
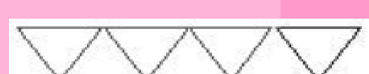
Roughness value Ra (μm)	Roughness grade number	Roughness symbol
50	N12	
25	N11	
12.5	N10	
6.3	N9	
3.2	N8	
1.6	N7	
0.8	N6	
0.4	N5	
0.2	N4	
0.1	N3	
0.05	N2	
0.025	N1	

Figure 16 : . Comparison table for all 3 ways of indicating surface roughness symbol

Alicona test

The surface roughness for a run-in part of the bearing shell was measured using a focus variation microscope of the Alicona Imaging GmbH

Deposit topography was observed and measured using a x20 objective lens. The vertical resolution was 10nm with focus variation measured according to EN ISO standard 25178. The measurements strategy was to create a 16 point grid across the interrogated surface and then compare against a clean baseline surface

The radii of the inserts measure during the proposed system were compared with those obtained using a variable focus3-D optical system(Alicona InfiniteFocus, Austria). Automatic radius estimation ofthe2-D dimension was carried out using the3-D surface images showing Figure 17. The points selected forcurve fitting were chosen from the edge pixels and the measurement was repeated three times one ach type of nose used inthiswork. The averageofthemeasuredradiiwascomparedwiththe measurement usingthescannerandtheproposedalgorithm [12]

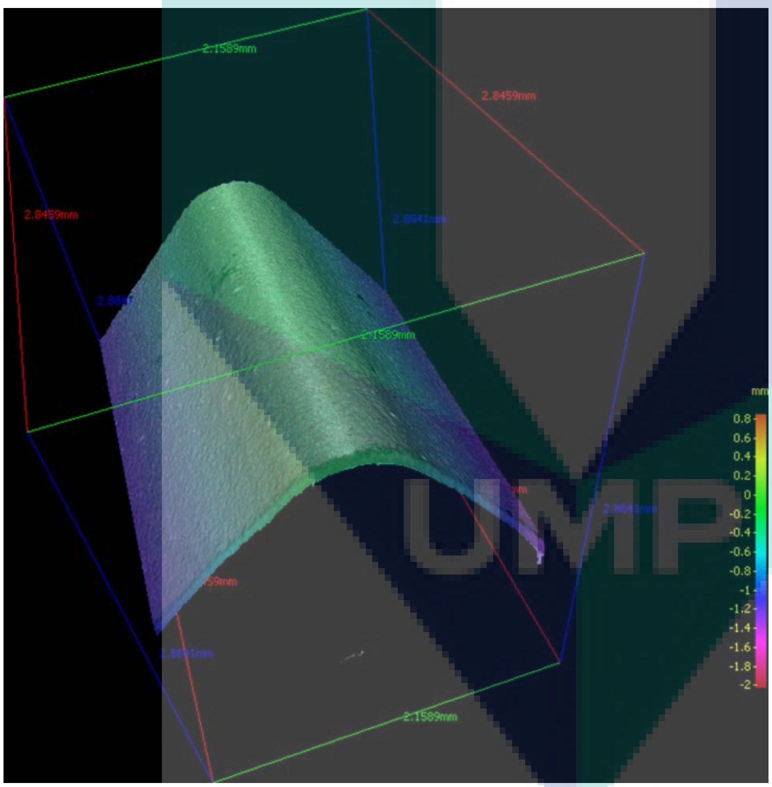


Figure 17 : A 3-Dsurfaceoftoolinsertusing Alicona InfiniteFocus system.

Thickness profiles of the wear tracks were measured before and after the 3-h tests with the alicona infinite focus profilometer, at 209 magnification as in Figure 18.

Figure 18 : Alicona 3D optical image of the tribofilm on the disc on tribofilm generated at 40 ^{o}C after the 3-h conditioning time

Scanning Electron Microscopy (SEM)

The method is use to determine the metallurgical properties of the deformed layer by sectioning the surface and examining the cross section. The use of SEM requires placing specimens in vacuum. In addition, for insulating specimens conductive coating is required. It have two major limitation which are difficult to derive quantitative data and inherently limited field of view because it show only few asperities whereas the salient point about surface contact is that involves wholes populations of contacting asperities As in Figure 19.

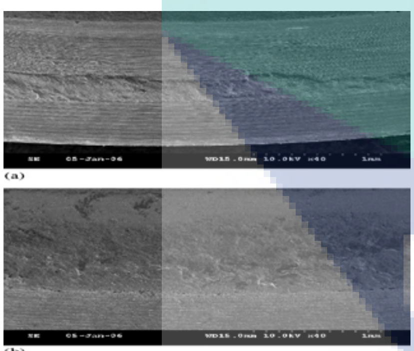


Figure 19: SEM micrograph of an worn valve and seat insert seating faces

Light Optical measurement

Usually the optical measurement are taking by usng the optical microscope, often referred to as the "light microscope", is a type of microscope which uses visible light and a system of lenses to magnify images of small samples. Optical microscopes are the oldest design of microscope and were possibly invented in their present compound form in the 17th century. Basic optical microscopes can be very simple, although there are many complex designs which aim to improve resolution and sample contrast. Originally images were captured by photographic film but modern developments in CMOS and charge-coupled device (CCD) cameras allow the capture of digital images. Purely digital microscopes are now available which use a CCD camera to examine a sample, showing the resulting image directly on a computer screen without the need for eyepieces. Example of image get from the computer or digital screen as below in Figure 20.

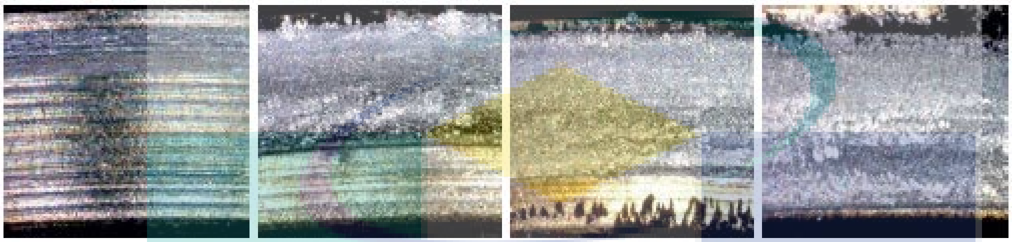


Figure 20: Example of display image frim computer or digital screen

4. FINDINGS

The discussion about the data results using perthometer and optical measurement to detect wear or recession. First and foremost, the variable that use in the project is number of engine cycle and type of fuel used. For first result, would investigate about the surface roughness, Ra that got from the PS1 software. The results from the software will compare between two types of fuel which are gasses fuel and gasoline fuel. Besides, comparison also made between before and after the experiment.

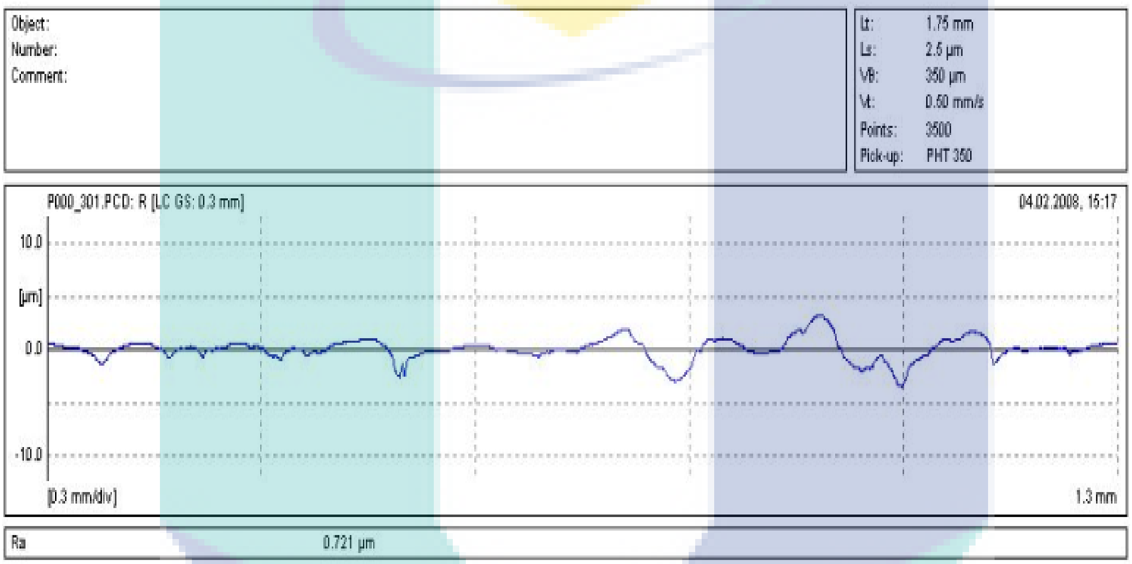
Next, the optical measurement would use to make inspections and measurement on the wear scar widths of the seating surface. Then, the wear mechanism and defect can be investigate and identify based on knowledge from previous references.

Surface roughness

Roughness is typically considered to be the high-frequency, short-wavelength component of a measured surface. However, in practice it is often necessary to know both the amplitude and frequency to ensure that a surface is fit for a purpose. Ra is the arithmetic average of the height of roughness component irregularities from the mean line measured within the sampling length. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces. Roughness is often a good predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion.

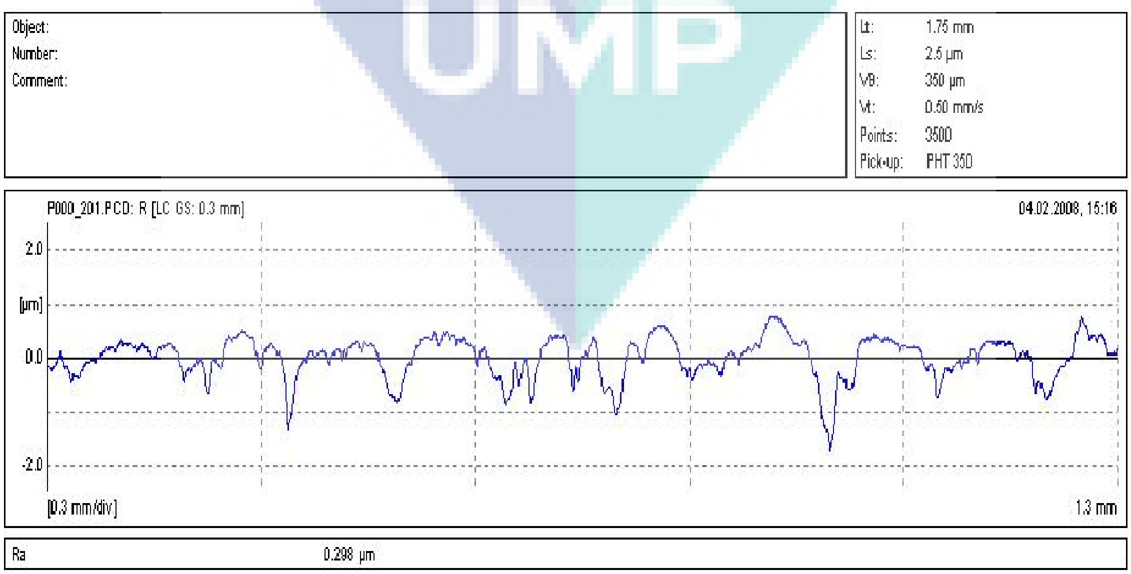
(a).Ra of unwear

1. Ra for x1



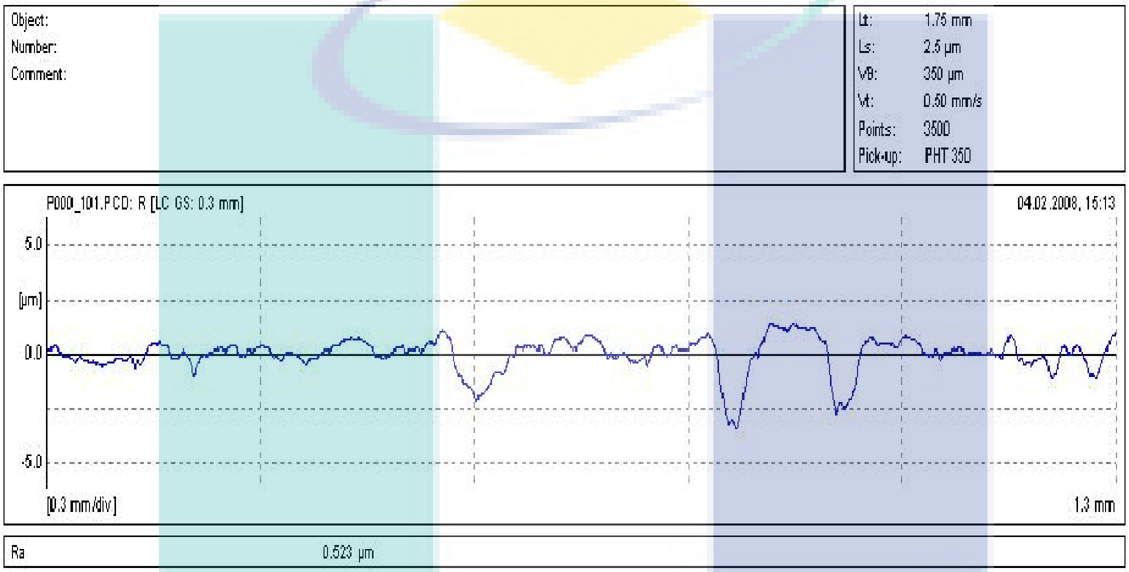
Ra = 0.721µm

2. Ra for x2



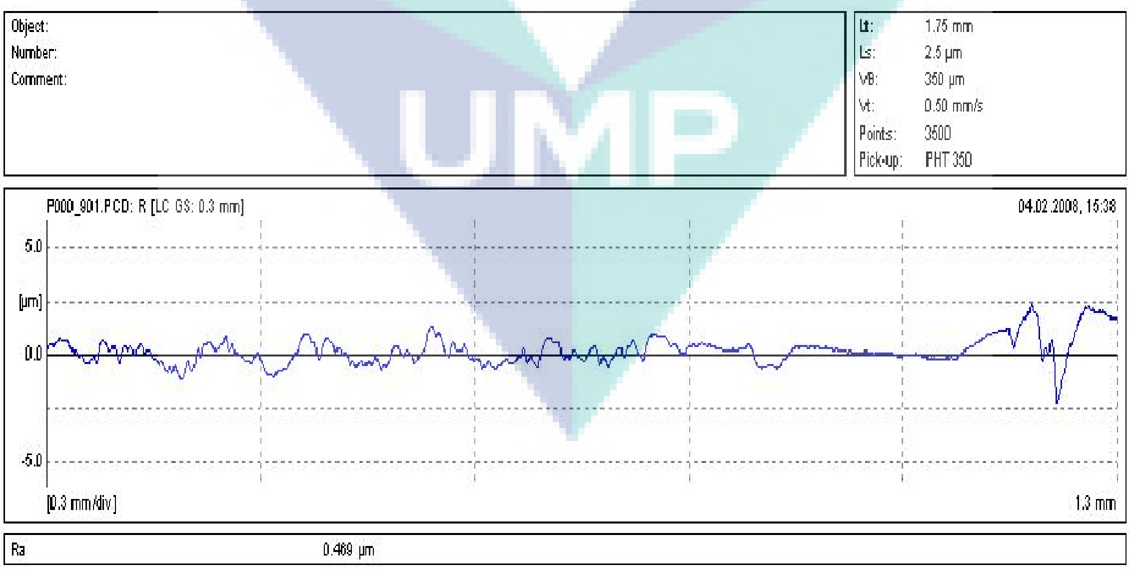
Ra = 0.298 µm

3. Ra for x3



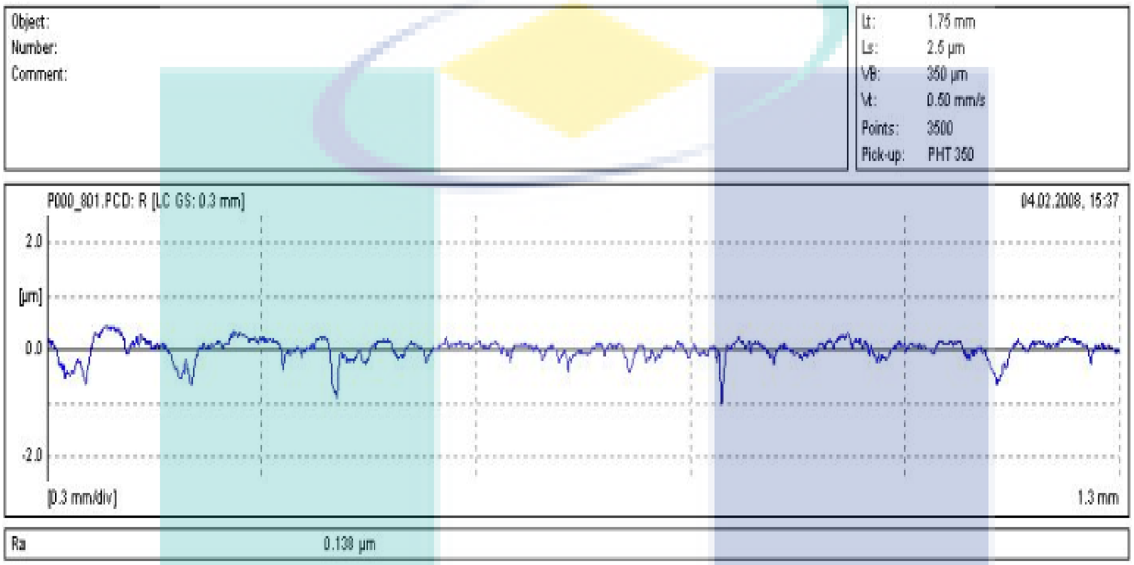
Ra = 0.523 µm

4. Ra for x4



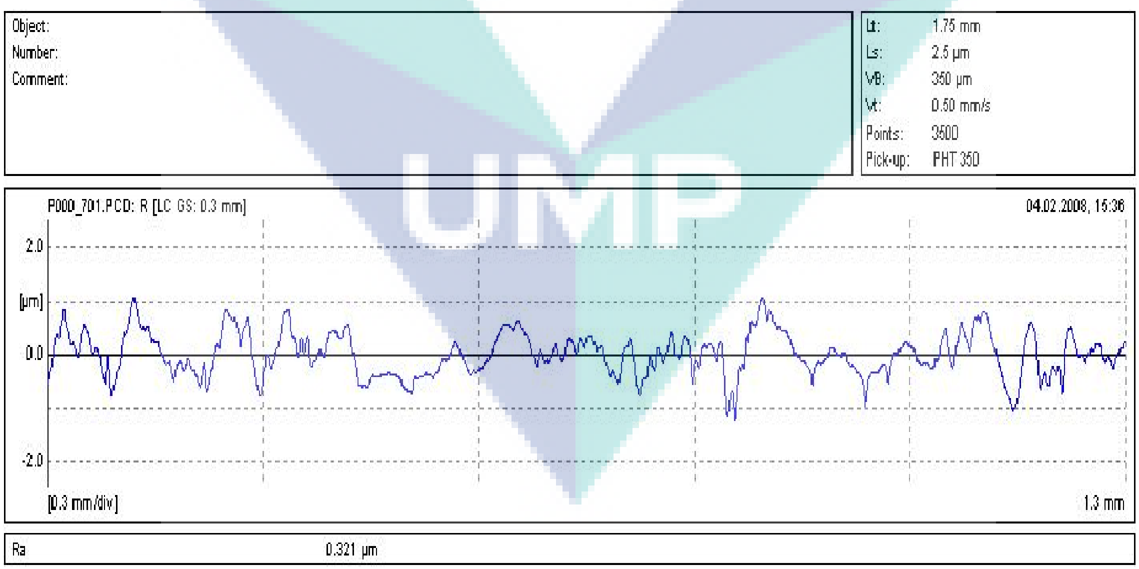
Ra = 0.469 µm

5. Ra for x5



Ra = 0.138 µm

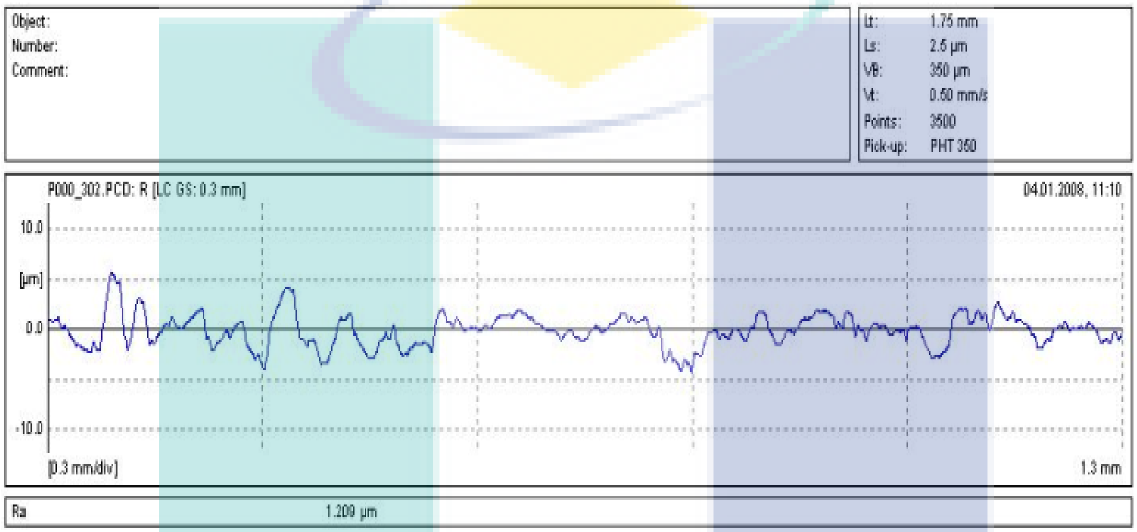
6. Ra for x6



Ra = 0.321 µm

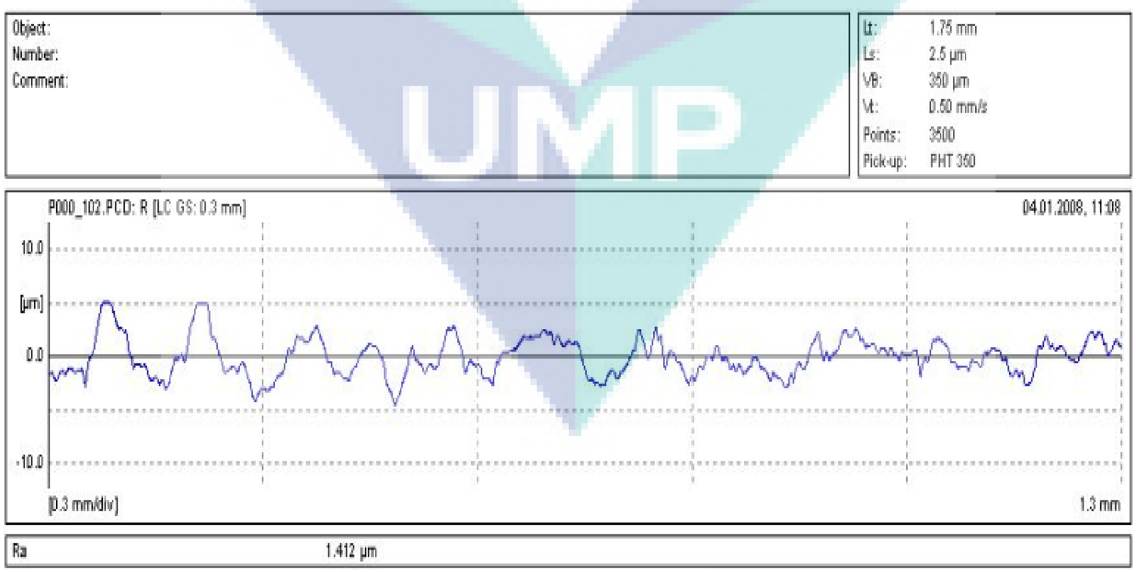
(b).Ra of wear on CNG

1. Ra for x1



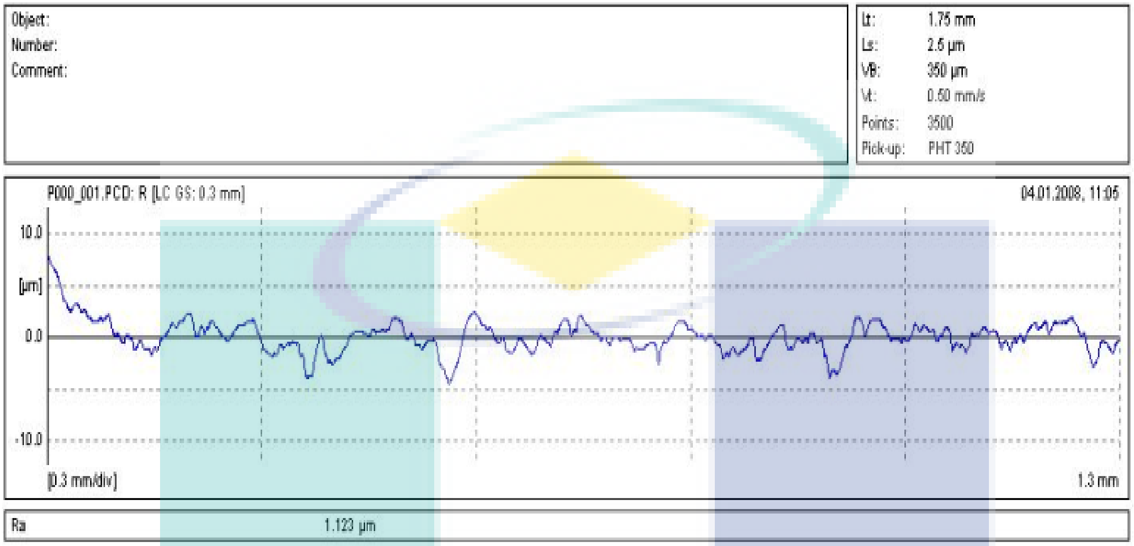
Ra = 1.209 µm

2. Ra for x2



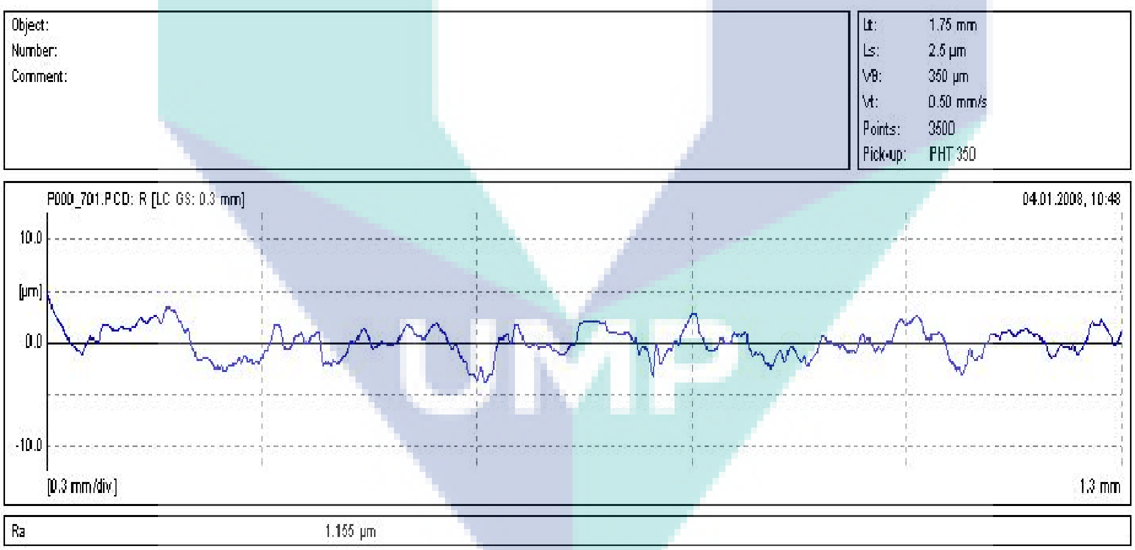
Ra = 1.412 µm

3. Ra for x3



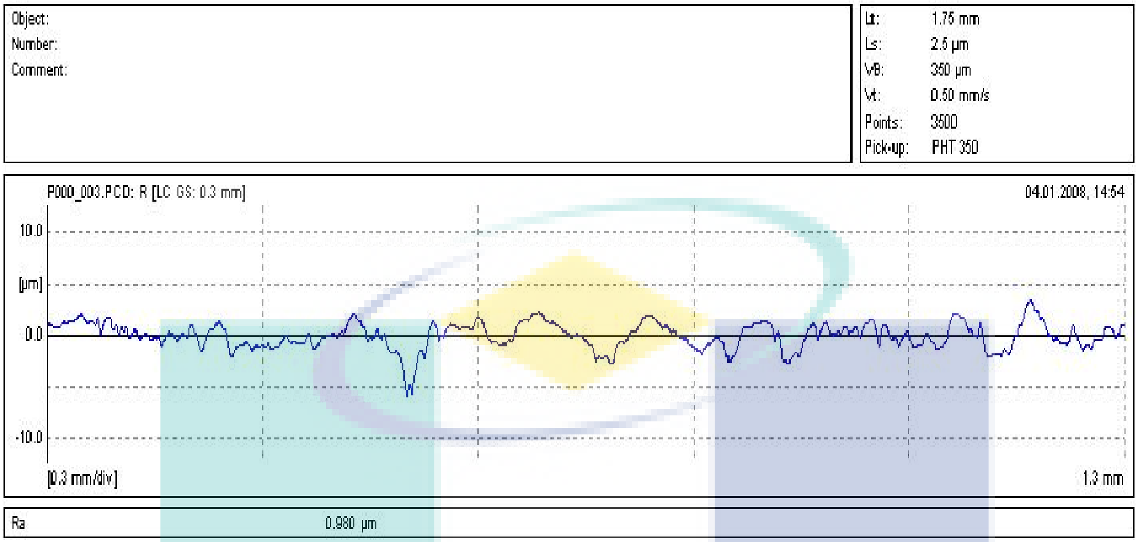
Ra = 1.123 µm

4. Ra for x4



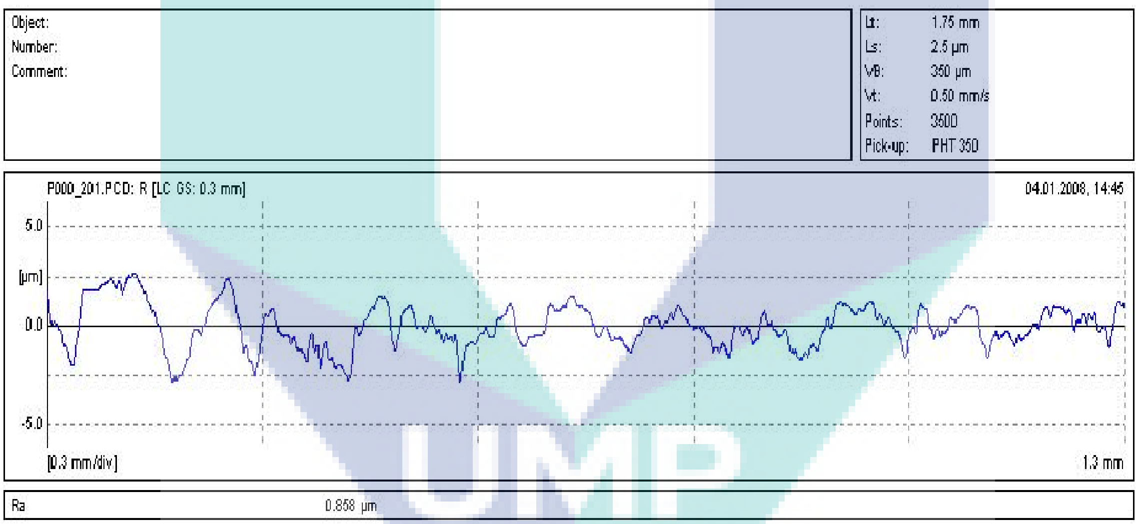
Ra = 1.155 µm

5. Ra for x5



Ra = 0.980 µm

6. Ra for x6

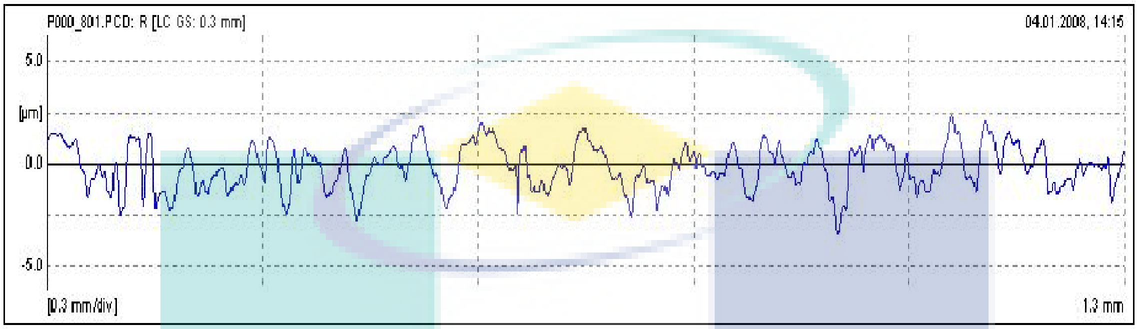


Ra = 0.858 µm

<u>(c).Ra of wear on petrol</u>

1. Ra for x1

Object:		Lt:	1.75 mm
Number:		Ls:	2.5 µm
Comment:		VB:	350 µm
		Vt:	0.50 mm/s
		Points:	3500
		Pick-up:	PHT 350

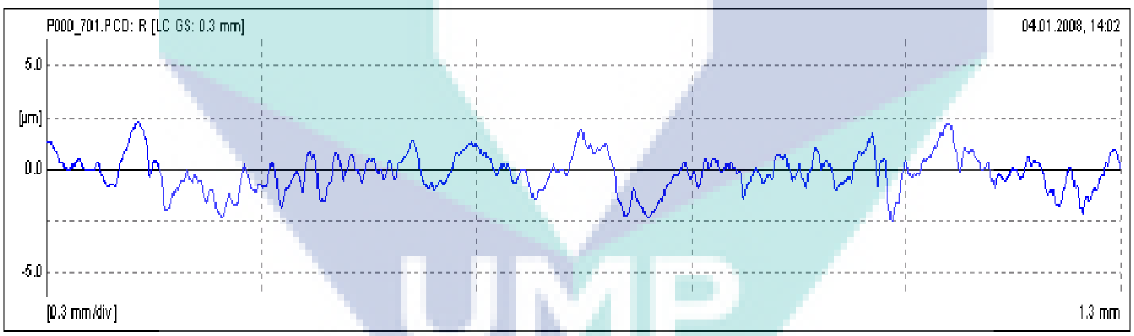


Ra	0.891 µm

Ra = 0.891 µm

2. Ra for x2

Object:		Lt:	1.75 mm
Number:		Ls:	2.5 µm
Comment:		VB:	350 µm
		Vt:	0.50 mm/s
		Points:	3500
		Pick-up:	PHT 350

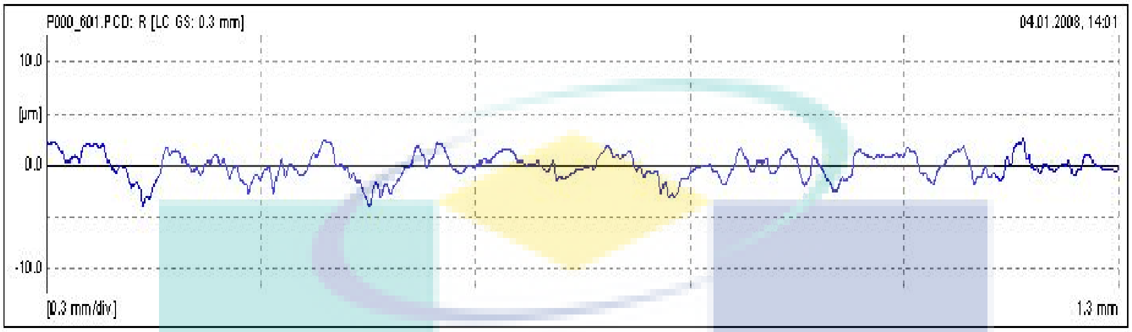


Ra	0.722 µm

Ra = 0.722 µm

3. Ra for x3

Object:		Lt:	1.75 mm
Number:		Ls:	2.5 µm
Comment:		VB:	350 µm
		Vt:	0.50 mm/s
		Points:	3500
		Pick-up:	PHT 350

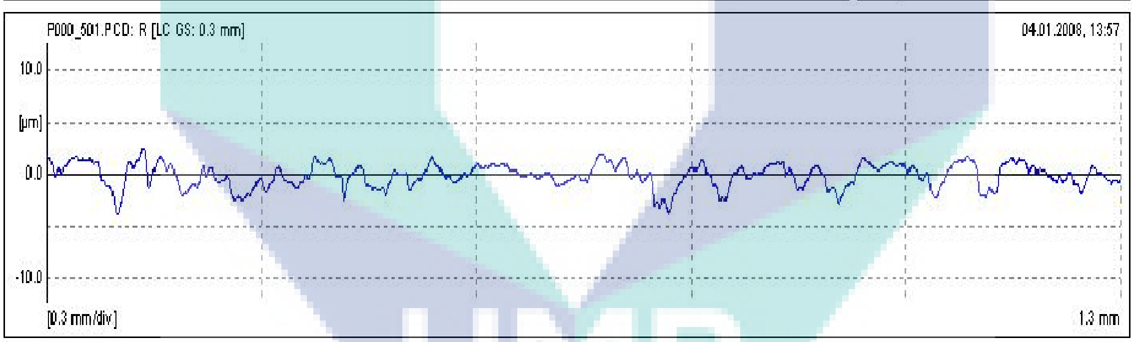


Ra	0.978 µm

Ra = 0.978 µm

4. Ra for x4

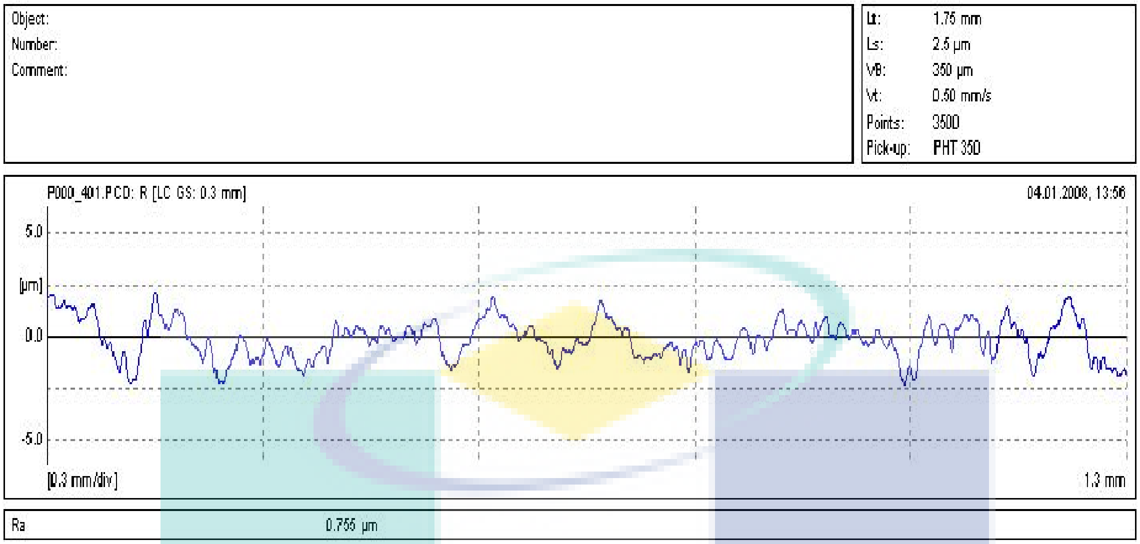
Object:		Lt:	1.75 mm
Number:		Ls:	2.5 µm
Comment:		VB:	350 µm
		Vt:	0.50 mm/s
		Points:	3500
		Pick-up:	PHT 350



Ra	0.896 µm

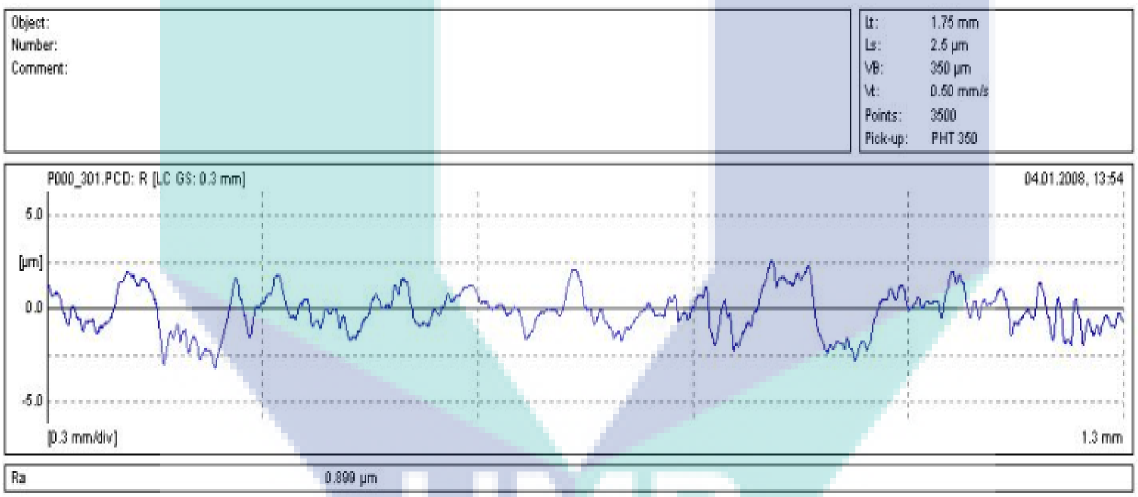
Ra = 0.896 µm

5. Ra for x5



Ra = 0.755 µm

6. Ra for x6



Ra = 0.899 µm

Figure 21. Characteristic surface profiles for (a) Ra of unwear, (b).Ra of wear on CNG and (c).Ra of wear on petrol

In the Figure 21 show graphs of surface roughness, Ra from the PS1 software. It shows that differences behavior of the graph affect the value of Ra. It is because the value of the Ra is influence by the height of the valley and peak besides the fluctuations based on the formula below

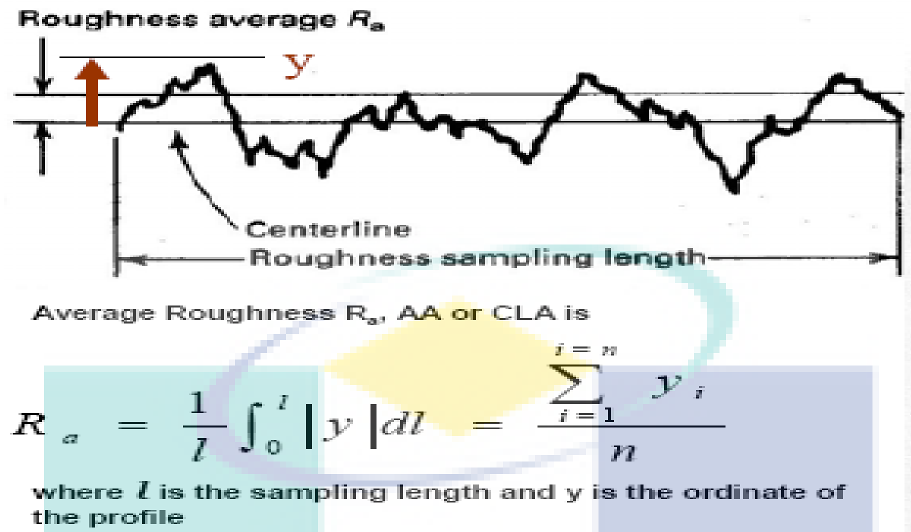


Figure 22 : Formula and graphical based of Ra

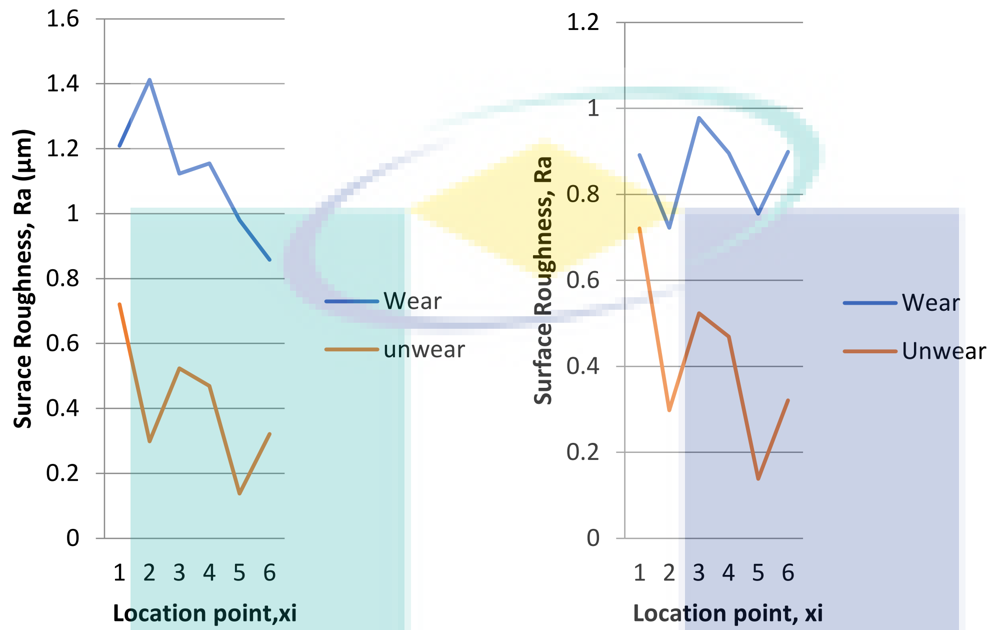
The value of Ra on Figue 21 (a) is lower than the Figure 21 (b) and (c) since the height of the valley and peak on Figure 21 (a) is lower than Figure 21 (b) and (c). Besides, the value of Ra on Figure 21 (b) is slightly higher than the on Figure 21 (c) because the higher in the height of the valley and peak consecutively.

From Ra that we can get on the conditions above, we can summarize it in the table below

Condition	**Cycle**	**Type of fuel used**	**Surface roughness,Ra (μm)**						**Average**
Wear	1200	CNG	1.209	1.412	1.123	1.155	0.98	0.858	1.123
	1200	Petrol	0.891	0.722	0.978	0.896	0.755	0.899	0.857
Unwear	none	none	0.721	0.298	0.523	0.469	0.138	0.321	0.412

Table 1 : Ra on the 6 point locations

In Table 1 , it shows that value of roughness for wear on CNG and Petrol is slightly higher than the unwear value. The average of roughness for CNG also is higher the Petrol. The percentage of average wear on CNG is higher about 172% than unwear whereas the percentage of average wear on Petrol is higher about 108% than unwear. Then, the percentage of wear on CNG is higher about 31% than wear on Petrol.

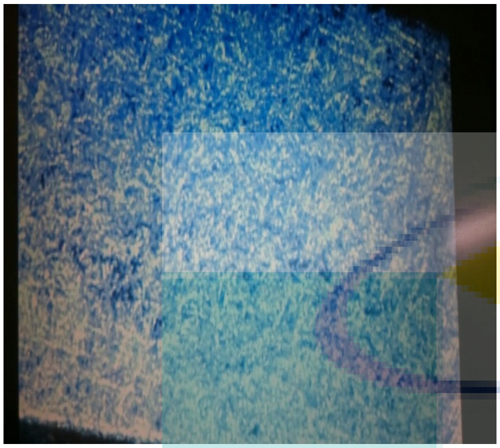


(a) CNG (b) Petrol

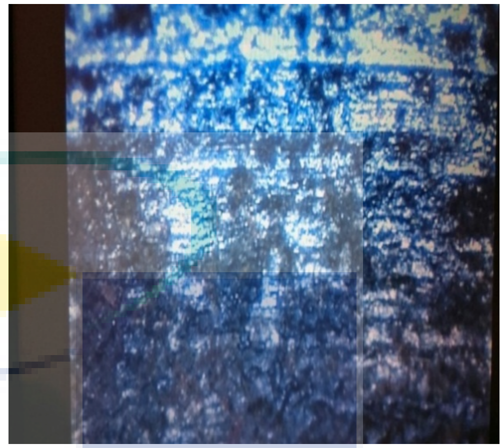
Figure 22 : Surface roughness, Ra vs Locatoin point, xi for (a)CNG and (b) Petrol

In the figure 22 is the graph get from the Microsoft Excell shows the comparison between the roughness on the CNG and petrol fuelled. The blue line shows the unwear value which is value of roughness,Ra before the wear experiment and the red line shows wear value which is value of roughness,Ra after the wear experiment. From the two graph, it show that unwear value are the same because using the same material but the wear value is difference which is CNG has higher value of roughness, Ra if compared to the Petrol.

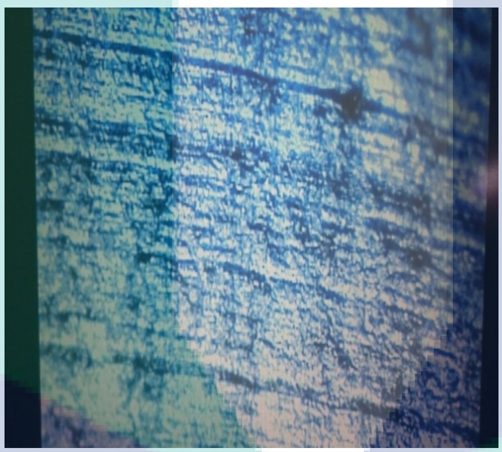
4.3 Optical measurement



(a) unwear



(b) wear(CNG)



(c) wear(Petrol)

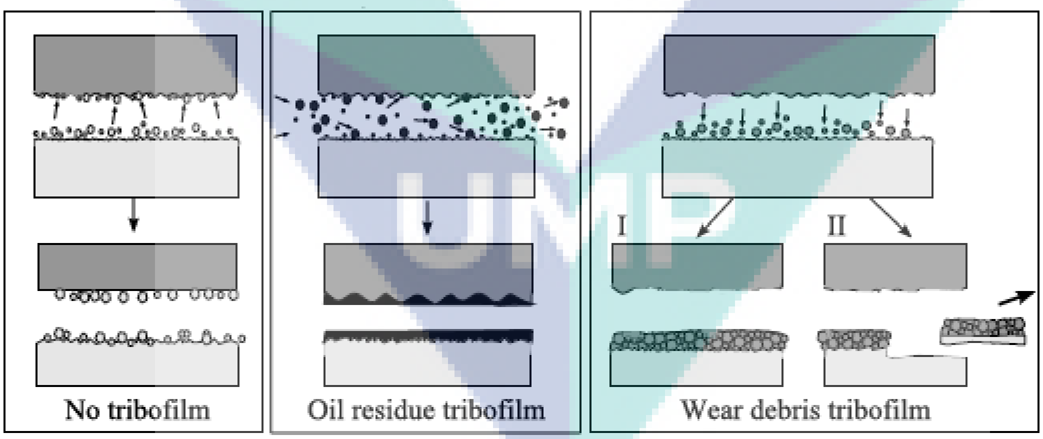
Figure 23: Wear scar for for CNG for (a) unwear , (b) wear(CNG) (c) wear(Petrol) using the optical measurement (Mahr Multisensor GmbH)

In the Figure 23 shows the optical measuement on the valve seat seating surface.The surface without the wear or unwear shows the clean wothout any damage as in Figure 23 (a). The wear on the CNG is actually running without any liquid fuelled meaning without any added oil, so its suffered a high wear rate, see Figure 23 (b). The sealing surfaces showed a none reflective wear scar with a damaged surface. Seen in the close-up, the – for the light optical microscope – none reflective surfaces are made up of rough surfaces covered with large amount of wear debris particles. The wearparticles mainly originate from the valve side and are found on both sides of the interface.

When wear with the addition of fully formulated oils which is petrol, the surfaces were not worn in the same way as in the test without added oil. Instead, the surfaces became covered with a protective oil residue tribofilm made up from additive residues from the oil, see Figure 4.3 (c). The oil residue tribofilm mainly covered the valve surface, but was also found on the valve seat insert surface. It has a smoothening effect, covering the original surface structure and protecting it. The tribofilm has flaked off in some places, revealing the original structure beneath, seen in the close-up. The oil residue tribofilm formation seems to be accelerated with the higher oil addition. At the lower addition rate, the oil residue tribofilm has not been able to give sufficient protection and the original surfaces have been worn down.

Tribofilm influence to the wear

For the tests with the non-additivated oil, the wear particles generated from the valve seat insert have agglomerated, creating a wear debris tribofilm on the valve surface. As long as the wear debris tribofilm is intact, it seems to protect against wear. However, it has a tendency to flake off, and in the process remove some of the underlying material, leaving a damaged appearance of the valve seat surface, as seen in Figure 4.2 (b). This failing of the tribofilm is higher for the higher oil flow, resulting in higher wear rate and worse surface appearance.



(a) **(b)** **(c)**

Figure 24 : Three surface characteristics. Source :[13]

In the Figure 24, show the surface characteristics which are:-

(a) Mechanism occurring in the ”driest” case, i.e. the reference tests without any oil addition to the air flow. Severe wear with wear particles – primarily from the valve surface – are found spread all over the contact surfaces.

c) Mechanism dominating for the fully formulated oils, which in the high flow case add enough oil-based particle residues to effectively fill up the crevices in the surfaces, creating a smooth protecting residue tribofilm.

d) Mechanism dominating for the non-additivated oil, involving formation of a smooth wear debris tribofilm on the valve by agglomeration of wear particles originating from the valve seat insert. This tribofilm has reduced the wear, especially for the low flow case. However, it has a tendency to delaminate and become sheared off, leaving a damaged surface structure. This delamination behavior has been more pronounced for the high flow rate and has accelerated the wear rather than protected the surfaces.

When in room temperature, a difference in the thermal expansion properties may induce residual stresses both within the tribofilm, between its different layers, and also between the tribofilm and the Stellite F material beneath. The residual stresses could increase the tendency of the film to flake off when highly loaded. If the tribofilm is too thick, the flaking could lead to a detrimental valve sealing leakage, quickly leading to guttering and failure of the valve seat seating surface.

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Tribochemical reaction

The composition analysis result of the tribochemical reaction product indicates that a large amount of O and C as well as S, V, Cu, Mn, Si and Al were detected. It was observed that the base metal of the valve and seat insert seating faces beneath the tribochemical reaction product was damaged. This signifies that wear occurred due to direct contact between the base metals of the valve and seat insert before the tribochemical reaction productwas formed and that it covers the contact area. It can be seen that there was material transfer between the valve and seat insert. From the surface or cross section of the tribochemical reaction product accumulated on the valve and seat insert seating faces, the compositions that exist only on the other mating specimen were detected in addition to the compositions of each base metal.

From the tribochemical reaction product of the valve seating face, the Cu, which was the composition of the seat insert, was detected. From the reaction product of the seat insert seating face, the Si and Mn, which were the compositions of the valve, were detected. The tribochemical reaction product covers the valve and seat insert seating faces. Since the level of the surface of the tribochemical reaction product is higher than that of the seating surfaces of the two base metals, the tribochemical reaction products contact with each other first before the two base metals of the mating specimen contact.

The tribochemical reaction product, being accumulated on the seating face, increases the average Ra and causes uneven contact when the valve is closed. This might deteriorate the gas tightness of the cylinder.

Wear mechanism on the surface

In a CNG condition there is very little exhaust residues which can build up a protecting film and hence have an atmosphere that is comparable to that of Petrol. For a material combination similar to the one investigated here, he observed that “during operation, very small portions of the valve seat are pulled from the seating face and deposited on the valve face due to adhesive deposition”. This resulted in an accelerated abrasive wear of the valve seat as the deposited material on the valve cause grooved on the valve seat surface due to rotation of the valve. The higher value of roughness lead to reduced valve seat area that cause decreased heat transfer possibilities and therefore also larger thermo related stresses. Before the wear and deposits have gone the whole rotation and creating a symmetrical pattern, which it eventually will, the valve will also suffer from bad valve sealing and higher local peak loads due to poor load distribution.

Several occurrences of corrosive wear on the surfaces were identified. The corrosive action has not only etched the outermost surface on the oxide but nalso etched out a piece of the valve seat material. It looks like one of the phases of the material has been left whereas the material around it has been consumed. Since Mo often is added to counteract the corrosion a qualified guess is that this is from within an area of high Mo content and it is the Mo-phases that have been spared. Whether this corrosion has taken place before the tribofilm was formed or if it is the forming process of the tribofilm itself that has caused the corrosion is hard to determine. The dominant wear mechanism of the valve seat material is oxidation by oxidising itself, or becomes covered by a new layer of tribofilm based on residues.

In cylinder pressure trace was monitored at 4,000 rpm. It showed at 4,000 rpm, the amount of pressure rise for the 1 mm DVL is more when compared to baseline CNG as shown in Figure 21. The peak pressure rises from 40.09 bar to 44.93 bar which is about 12% . Even though the ignition is the same for baseline CNG, the turbulence enables more complete burning which translates to higher pressure rise. The rise in experimental value is more than the CFD prediction. The CFD approximation only assumes air fuel ratio is fixed, where else in the experimental fuel deposits from crevices and some exhaust gas recirculation (EGR) maybe present to cause more pressure build up. It can be said that, the 1 mm DVL causes the flame to move faster as the overall gradient improves as shown in Figure 22 for the mass fraction burn.

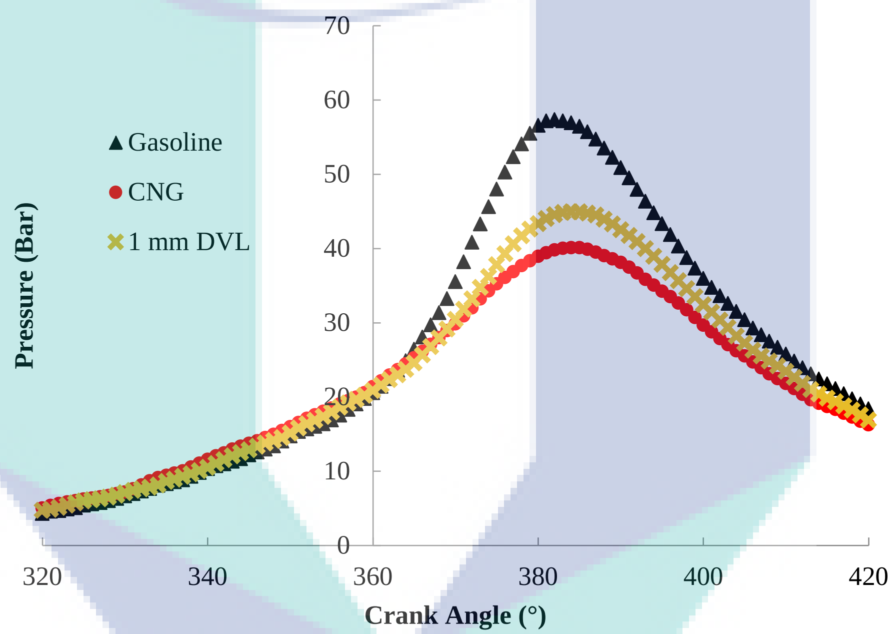

Figure 21Pressure trace at 4000 rpm for Gasoline, CNG Baseline and 1 mm DVL

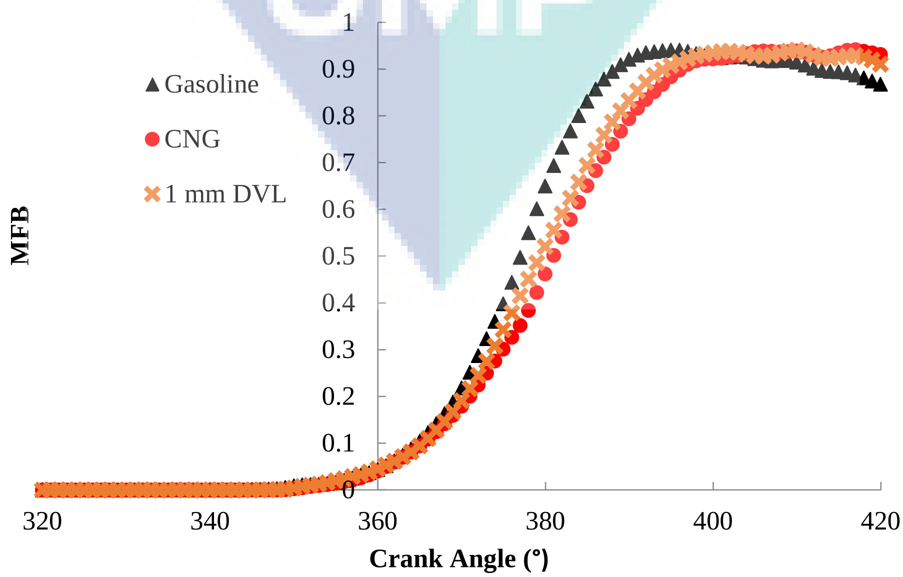

Figure 22 MFB at 4000 rpm for Gasoline, CNG Baseline and 1 mm DVL

The rate of heat release (ROHR) analyzed from the pressure trace is also compared to find the improvement due to DVL. As shown in Figure 23, the value of the heat release shows slight improvement in peak heat release compared to CNG baseline (Ramasamy et al., 2014). However, the burning of the fuel is still late as the gasoline burns completely at 34 °ATDC while CNG and 1 mm DVL is still burning beyond this point.

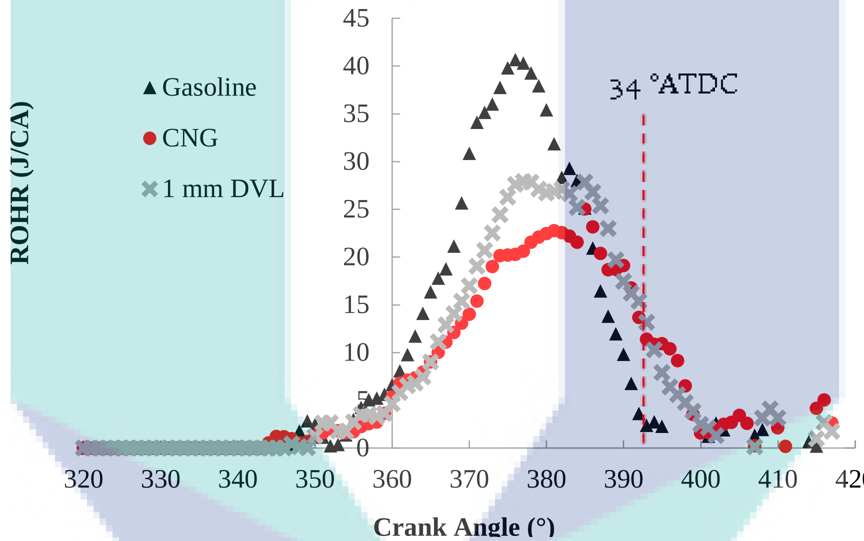

Figure 23 ROHR at 4000 rpm for Gasoline, CNG Baseline and 1 mm DVL

5. CONCLUSION

Based on the project, which is analysis of valve seat recession on CNG fuelled engine that is used in the vehicle industries, some of the things that need to be concern are the wear tester and the surface analysis. Research have been done by considering the variable for wear tester experiment which are the cycle number, speed rate, times, valve closing velocity and type of fuel. After the wear tester, the surface analysis is done.

As a conclusion, while the cycle number increased, the average Ra of the valve seat seating faces increased linearly. The type of fuels also influence to the average Ra which is higher average Ra would produce when CNG is used than the petrol with the percentage of about 31%. Besides, Ra whereby give influence to the wear scar that will affect the wear mechanism which cause abrasive wear, corrosive wear and tribofilm. It seem that wear is current problem on the valve seat seating faces when using the CNG fuel.

ACHIEVEMENT

i) Name of articles/ manuscripts/ books published

M. Hassan, M. Sakinah, K. Kadirgama, D. Ramasamy, M. Noor, and M. Rahman, "Tribological Behaviour Improvement of Lubricant Using Copper (II) Oxide Nanoparticles as Additive," *World Academy of Science, Engineering and Technology, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering,* vol. 10, pp. 350-358, 2016.

Y. Muthusamy, K. Kadirgama, M. Rahman, D. Ramasamy, and K. Sharma, "Wear analysis when machining AISI 304 with ethylene glycol/TIO2 nanoparticle-based coolant," *The International Journal of Advanced Manufacturing Technology,* vol. 82, pp. 327-340, 2016.

M. Sakinah, A. Amirruddin, K. Kadirgama, D. Ramasamy, M. Rahman, and M. Noor, "The Application of Response Surface Methodology in the Investigation of the Tribological Behavior of Palm Cooking Oil Blended in Engine Oil," *Advances in Tribology,* vol. 2016, 2016.

Sakinah Hisham, K. Kadirgama, D. Ramasamy, M.M. Noor, A.K. Amirruddin, G. Najafi, M.M. Rahman, Waste cooking oil blended with the engine oil for reduction of friction and wear on piston skirt, Fuel, Volume 205, 2017, Pages 247-261, ISSN 0016-2361, https://doi.org/10.1016/j.fuel.2017.05.068.

(http://www.sciencedirect.com/science/article/pii/S0016236117306543)

Keywords: Coefficient of friction; Wear rate; Waste cooking oil; Engine oil

D. Ramasamy, Z.A. Zainal, K. Kadirgama, Horizon Walker-Gitano Briggs, Effect of dissimilar valve lift on a bi-fuel CNG engine operation, Energy, Volume 112, 2016, Pages 509-519, ISSN 0360-5442, https://doi.org/10.1016/j.energy.2016.06.116.

(http://www.sciencedirect.com/science/article/pii/S0360544216308908)

Keywords: CFD; Compressed natural gas; Spark ignition engine; Swirl number

ii) Title of Paper presentations (international/ local)

iii) Human Capital Development

Masters

1. MAIZATUL ASNIDA BINTI HASSAN 900815085644 MMM14041

2. SAKINAH BINTI MUHAMAD HISHAM 900407055358 MMM14027

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4. RADIN AFIQ BIN RADIN ABD HALIM MC11037

iv) Awards/ Others

CITREX 2015

Members

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11185	DEVARAJAN A/L RAMASAMY	781102075113	UMP	Automotive Engineering Centre (AEC)	

Title of Participation	TRIBOLOGICAL WEAR TESTER
Category	National
Medal/Certificate	
Year	
Exhibition Venue	UMP Sports complex
Attachments	Poster CITREX2015 Deva Wear Tester.pdf

ITEX 2016, KLCC

Members

Researcher ID	Name	IC/Passport Number	University	Faculty/School/Centre/Unit	Position
11685	KumaranKadirgama	810304045123	UMP	Faculty of Mechanical Engineering	
11185	DEVARAJAN A/L RAMASAMY	781102075113	UMP	Automotive Engineering Centre (AEC)	

Title of Participation	Dissimilar Cam Profile for Airflow Improvement in a CNG Engine
Category	National
Medal/Certificate	
Year	
Exhibition Venue	KLCC, KL
Attachments	POSTER-02 version 2_deva2016_final.pdf

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Category	National
Medal/Certificate	
Year	
Exhibition Venue	SIFF, Korea
Attachments	BIS POSTER UMP TEMPLATE 2016 - Deva.pdf

v) Others

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