Testing on the Piston Rings

The various type of testing performed on the piston rings is to provide the best quality of piston rings, so that performance of the IC Engine can be increased as much as possible. Some of testing which are used on the piston rings from the starting (casting of rings) to the final product is mentioned below,

2.1 Microstructure Testing

The microstructure of the coating was studied under the optical microscope. To study the microstructure a piece of the track of coating was cut and then fixed in the thermosetting plastic to hold it. The fixing of the small piece of the coating piece was done on the automatic mounting press as described earlier in micro hardness test. The cross section of worn surfaces was analyzed, when the pin was sliding over the coating material there was a generation of heat which might result in change in the microstructure. It is known that the melting point of the aluminum is 662˚C [1] and when there is rise in temperature above recrystalisation temperature then there occurs a change in the microstructure. [4].

2.2 Chemical Composition Testing (using SEM/XRD/EDS)

Energy dispersive spectroscopy (EDS)

After 12 months of exposure, the 25*25*280 mm specimens used for the expansion test were also used for chemical analysis using quantitative Energy Dispersive Spectroscopy (EDS). Thin 25*25*10 mm samples were cut from original specimens exposed to sodium sulfate solution as shown in Fig. 4. These samples were polished using 300 and 600 grit polishing papers and the 25*25 mm cross sections were marked using a sharp tipped pencil to generate a grid mesh as schematically shown in Fig. 5. The exterior layer is hereby called EXT and the interior portion is called INT for comparison purposes. A novel SEM-EDS setup was used and the quantitative compositional analyses of exposed samples were obtained using window scanning option with an area of 1 mm2 for each grid point.

2.3 Mechanical Strength (Micro Hardness)

The 25*25*10 mm thin specimens used for EDS were also used for micro-hardness testing to understand the mechanical changes on the exposed samples. Micro-indentation is a common method of evaluating the quality of materials for engineering purposes, in particular ductile materials (i.e. metals) but also brittle materials such as concrete [27,28]. This technique is based on applying a static load for a known period of time and measuring the response in terms of size of indentation. The Vickers hardness HV (GPa) is calculated per Eq. (6) in which P (Kgf) is the applied force, a is the indenter diagonals angle equal to 136 and D (mm) is the average of diagonals of the indentation [29, 30] In this study, a 0.2 Kgf load was applied on the samples for 15 s, followed by a measurement of indentation size using an optical microscope. For each grid point, three replicate indentations were made as shown in Fig. 6a and the average values were used for calculating the hardness values. Fig. 6b shows an SEM image of the indentation performed on a cement paste sample

2.4 Adhesion Testing

The adhesion strength of coatings deposited plasma arc spray (H_2 or N_2 as carrier gas) was tested. The thermally sprayed coatings were deposited in accordance with the recommendations of our experiment design, with the exception of the large splat coatings, where the parameters were slightly altered. The deposition parameters used in the plasma arc spray process are mentioned in the table XXXX. The coatings and their chemical compositions can be seen fromTable 1. Metcoloy 2 (wire) and Metco 3007 (powder) are standard products manufactured by Sulzer Metco. The size grades for the powder used with plasma arc spray process were 50 µm, respectively. The thicknesses of the coatings were in the range 1.5-2.5 mm for arc spray and 205 µm for the hard chrome plating. As substrate, piston rings made up of cast iron , were chosen. The surface roughness of the arc sprayed and hard chrome deposited substrate 3-4mm & 8-10mm, respectively (Ra-values). The Metcoloy 2 and 80Ni20Al materials were supplied as the two separate electrodes in the arc spray process, resulting in a coating consisting of 50% of each material. Two different arc spray droplet sizes, 50 and 200 mm, were examined for the Metcoloy 2q 80Ni20Al-coating.The adhesion of the coatings to the substrate was tested with the methods as described with the simple bending equipment as described below [76].

2.5 Wear testing on the piston rings Coatings

2.5.1 Types of wear test of piston rings coating:

Wear behavior of the can be measured on the different test and is mainly depends on the application of the coating and thickness of the coating. The test is carried out at different wear conditions and the parameter are taken into consideration on which the wear is mainly depends. These tests are such mainly divided into these categories:

2.5.2 Scratch test of piston rings coating:

The scratch tester is used to test the scratch resistance of flat solid surfaces such as coatings, metals, ceramics, composites, polymers, and other material surfaces. The test is performed by sliding a stylus over the surface of the test specimen. The normal load, sliding speed, direction, stylus geometry, and stylus material can be varied. The resultant tangential force at the contact interface can be monitored using tribodata, the supplied windows-based data acquisition Software. The onset of scratch or adhesion failure of coatings can be inferred from this data. A CMOS camera is built-in to capture the scratch scar image. (Y. Xie et al. Y. Xie, H.M. Hawthorne, 1999) was investigated scratching an alumina coating, using conical diamond indenters with different tip radii under either progressively increasing or constant loading. The interaction between the coating and the indenter was studied by performing single scratching on a polished virgin surface, repeated scratching over the same track and closely-spaced, multiple parallel interacting scratching.

2.5.3 Slurry Abrasion Test of piston rings coating:

The Slurry Abrasion Tester is used to test the abrasive resistance of solid materials to slurry compositions. Slurry erosion problems are especially important during rainy seasons in hydroelectric power plants due to the increase in the number of solid particles impacting the surfaces, especially in systems where the installation of an exhaustive filtration process is not possible [83]. Various materials such as metals, minerals, polymers, composites, ceramics, coatings, and heat-treated materials can be tested with this instrument. The test is performed by rotating a rectangular test sample within a cup filled with abrasive slurry (figure 2.1). The mass of the test sample is recorded before and after conducting a test and the difference between the two values is the resultant mass loss due to slurry abrasion [84].

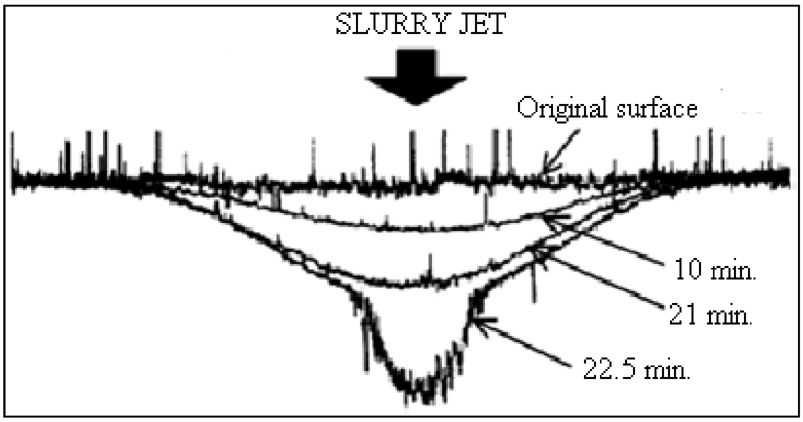

Figure 2.1 Slurry abrasion wears of thermal spray coating

To develop a comparison table for ranking different materials with respect to each other, it is necessary to convert this mass loss to volume loss to account for the differences in material densities. The test speed, temperature, duration, as well as test sample size and slurry composition, can be varied. The instrument is configured to run up to six test samples simultaneously at the same speed. The test temperature is maintained by immersing the slurry vessels in a water bath.

2.5.4 Friction Test of thermal spray coating:

The Friction Tester is used to test the frictional characteristics of materials in dry or lubricated reciprocating motion contact. A wide variety of materials including fluid lubricants, greases, cutting fluids, metals, composites, ceramics, polymers, and coatings can be tested. The test is performed by loading the test specimen against a ball, pin, or cylinder undergoing reciprocating linear motion. The frictional force developed at the contact interface is measured by a force transducer. The output signal can be captured by a storage oscilloscope or tribodata, Koehler's data acquisition software, for evaluation. The reciprocating motion of the ball results in a unique velocity profile which allows for monitoring of static and dynamic friction force over a wide range of linear sliding speeds. The test load, stroke, frequency, and temperature can be adjusted to simulate different testing conditions. Wear testing may also be performed on the test specimen by evaluating the resulting wear scar with a profilometer. Yucong Wang et al. (Yucong Wang, Simon, Tung, 1999) were performed with a modified Cameron Plint reciprocating machine to determine the scuffing and wear behavior of piston coatings against 390 Al engine cylinder bore. The tested piston coatings included nickel–tungsten (Ni–W).plating, electro less Ni plating, Ni–P coatings with ceramic particles such as boron nitride (BN), Sic, as well as titanium nitride physical vapor deposition (PVD) coating, diamond-like carbon (DLC) coating, and hard anodizing.

2.5.5 Air Jet Erosion Test of thermal spray coating:

The Air Jet Erosion Tester is used to test the erosion resistance of solid materials to a stream of gas containing abrasive particulate. The test is performed by propelling a stream of abrasive particulate gas through a small nozzle of known orifice diameter toward the test sample. Material loss, in this case, is achieved via the impingement of small abrasive particles upon the surface of the test sample. Materials such as metals, ceramics, minerals, polymers, composites, abrasives, and coatings can be tested with this instrument [84]. The test specimen, temperature, angle of incidence of the jet stream, abrasive particulate speed and flux density, can be varied to best simulate actual conditions. Special adapters are available to test various geometries and components for user-specified testing applications.

2.5.6 Pin on Disc Test of thermal spray coating:

The Pin-On-Disc Tester is used to test the friction and wear characteristics of dry or lubricated sliding contact of a wide variety of materials including metals, polymers, composites, ceramics, lubricants, cutting fluids, abrasive slurries, coatings, and heat-treated samples. The test is performed by rotating a counter-face test disc against a stationary test specimen pin (figure 2.2). The advantage of a wear test, when compared to indentation or scratch testing, is that it can give a measure of the lifetime of a particular coating-substrate system. In many applications of coatings, the resistance to wear can be more important than the load required to permanently damaging the material [86]. A spherical ended pin has the advantage that contact conditions can be relatively well controlled. No matter the degree of misalignment between pin axis and disk axis the initial apparent area of contact should be the same, for a given load. However, the apparent area of contact will then change during the test up to the maximum given by the pin-diameter Garcia-Prieto, M.D. Faulkner, J.R. Alcock, 2004. The pin on disc test can be used for a variety of coatings it may be thick or thin and can be made of any material such as metals, ceramics, cermets and composites (Binshi Xua, Zixin Zhua, Shining Maa, and Wei Zhang, Weimin Liu2004, , Y. Iwai a, T. Honda,

H. Yamadaa, T. Matsubara, M. Larsson, S. Hogmarkd 2001, Jeffree, C. E.; Read, Ambient- and Low-temperature scanning electron microscopy, Electron Microscopy of Plant Cells, London: Academic Press. pp. 313–413. ISBN 0123188806, Karnovsky, A formaldehyde-glutaraldehyde fixative of high osmolality for use in electron microscopy, Journal of Cell Biology 27: 137A).

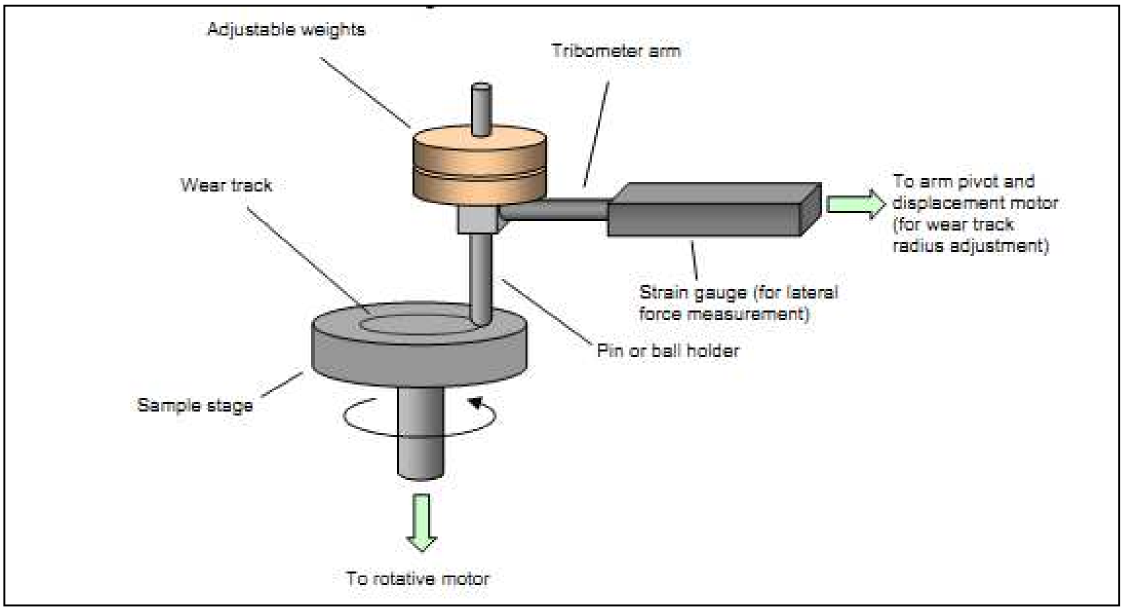

Figure 2.2 Pin on disc wear test of thermal spray coating (Reference 40)

There are various wear measurement methods available for assessing changes in the tribological system in terms of wear behaviour. Depending on the method used data can be obtained on mass wear, volumetric, localized or integral wear behaviour, and wear forms. All these methods are legitimate for particular problems but differ greatly in complexity

For high wear rates, the wear volume can be determined from macro geometrical changes or mass loss. In addition to sliding wear, surface degradation of piston rings can take place due to blow-by of hot gases from the combustion chamber, where the temperature of the combustion gas is in the excess of 2 000℃. The blow-by can cause local melting or hot gas erosion damages, or burn scars, on the rings. In engines where ring deterioration owing to blow-by is likely to occur, the use of molybdenum or similar heat-resistant coatings is essential [91].

Besides the established PVD coatings for the wear protection of machining tools, this paper deals with coating development and model wear test results from PVD coatings on piston rings for combustion engines. Piston rings are examples for the application of thin films on commonly used mechanical components. The PVD Cr_xN coatings are deposited by RF magnetron sputtering and characterized by their fundamental mechanical properties like thickness, hardness, residual stress and adhesion, which are important for the tribological behaviour of the coating substrate compound. The contact mechanics of the tribological system piston-ring–cylinder are determined by high mechanical loading and changing geometry caused by the sliding kinematics. Therefore, the range of thickness is about 7 mm. The selected rings are made of steel DIN 1.4112 (DIN X 90CrMoV18) with a bore diameter of 97.5 mm. The results of the coating substrate characterization — high hardness, moderate compressive residual stresses and sufficient adhesion on metallic substrates — provide good behaviour of coatings in this tribological application. This is confirmed by the results of the tribological test procedures which have been performed with ring-on-disc model-wear tests and a short-stroke test rig [92].

The wear of piston rings and cylinder liners can be accelerated by three-body abrasive wear caused by minor abrasive particles in the lubricating oil. The contaminant particles causing the three-body abrasive wear can originate from the oil sump or from the combustion chamber. In addition to the two-body and three-body abrasive wear, the overall wear rate can be tribochemically accelerated by aggressive components in the lubricant that have been entrapped in the ring zone. Aggressive combustion products are formed in particular when highly sulphuric fuels are used. Concerning most tribological applications, literature on the influence of the tribochemical wear on the overall wear of piston rings is only available to a rather limited extent. Experiences of chromium plated piston rings show that they offer good protection against wear caused by acidic combustion products [93].

Under conditions of poor lubrication, strong adhesive forces between the piston rings and cylinder liner may occur, leading to piston ring scuffing that comprises high friction forces and the formation of severe wear scars on the piston, ring and cylinder surfaces. As presented by Coy in his qualitative wear transition model, conditions of hydrodynamic lubrication at the mid-stroke region of the piston motion give rise to full film lubrication ($\lambda > 5$) and zero wear, while sliding under less favorable conditions in the vicinity of the dead centers of the piston motion cause mixed lubrication ($\lambda = 1...5$) and wear inversely proportional to the oil film thickness [94].

For low wear rates, the wear volume of piston rings can be determined by comparison of surface roughness profiles or cross section profiles before and after the tests (Shuster et al., 1999). Alternatively, the wear can be estimated from changes in relevant surface roughness parameters representing certain proportions of the piston ring face surface area [95].

It is commonly assumed that the wear of piston rings proceeds according to a mild mechanism of mild two-body abrasive wear against the cylinder liner, expressed by the formulae presented by Archard, Archard and Hirst, Preston, Rabinowitcz or Holm, while in reality the wear process is significantly more complicated[96].

The wear interaction between piston ring and piston groove in a radial piston hydraulic motor was studied in regard to mass loss and changes in form and surface roughness. A specially developed test rig that simulates the tilting movements of pistons at the end of strokes was used in the test. The results show that wear on the piston ring groove can be up to 10 times greater than the wear on the piston ring. For both interacting surfaces, the dominant wear mechanism was mild wear [75].

Laboratory tests to evaluate piston ring and cylinder liner materials for their friction and wear behavior in realistic engine oils are described to support the development of new standard test methods. A ring segment was tested against a flat specimen of gray cast iron typical of cylinder liners. A wide range of lubricants including Jet A aviation fuel, mineral oil, and a new and engine-aged, fully formulated 15W40 heavy duty oil were used to evaluate the sensitivity of the tests to lubricant condition. Test temperatures ranged from 25 to 100 8C. A stepped load procedure was used to evaluate friction behavior using a run-in ring segment. At 100 8C, all lubricants showed boundary lubrication behavior, however, differences among the lubricants could be detected. Wear tests were carried out at 240 N for 6 h at 100 8C with new ring segments. The extent of wear was measured by weight loss, wear volume and wear depth using a geometric model that takes into account compound curvatures before and after testing.

Wear volume by weight loss compared well with profilometry. Laboratory test results are compared to engine wear rates [77].

Two new substoichiometric titania (TiOx) coatings designated for cylinder liner application were deposited on specimen of grey cast iron GG20HCN with high carbon content by plasma spraying. First, a TinO2n−1 coating was prepared by atmospheric plasma spraying (APS) using a sintered and agglomerated Magneli-type spray powder. Second a TiO ´ 1.95−x coating was deposited with a vacuum plasma spray (VPS) process using a commercial, fused and crushed TiO1.95 powder. The tribological behaviour of these coatings under lubricated conditions was compared with uncoated specimen of this grey cast iron. As counter bodies a widespread used APS-sprayed Mo-NiCrBSi piston ring coating (MKP81A®), an advanced HVOF-sprayed WC/Cr3C2-based (MKJet502®) ring coating as well as non-commercial prototype APS-sprayed TinO2n−1 and APS sprayed (Ti, Mo)(C,N) + 23NiMo (TM23-1) coatings were tribotested. The interaction of the pairs with prototype engine oils based on esters and polyglycols were studied under mixed/boundary lubrication using the BAM test method. Lubricants were factory fill engine oils, ester-containing lubricants with low-SAP (sulphur–ash–phosphor) and/or bio-notox properties as well as polyglycole-based lubricants. The ester and polyglycole-based engine oils respond both to bio-no-tox criteria and are polymer-free. They follow different strategies to reduce zinc, phosphorus and sulphur to assure low ash content. Both TiOx coatings designated for cylinder liners meet or exceed the wear resistance of the grey cast iron with high carbon content when paired with APS-sprayed TinO2n−1 or Mo-NiCrBSi piston ring coatings. Overall, in nearly all pairs the wear rates of the APS TinO2n−1 coating were lower than those of the VPS TiO1.95−x coating.In order to characterize the tribological behaviour under oil-off, dry-running conditions, additional tests were performed under unlubricated unidirectional sliding conditions at 22 and 400 ^{0}C for a sliding speed of 1 m/s against sintered polycrystalline Al2O3 as stationary specimen [78].

The piston system accounts for roughly half of the mechanical friction of an internal combustion engine, thus it is important to optimize. Different thermally sprayed cylinder liners were investigated in order to optimize the frictional impact of the contact between cylinder liner and piston ring/piston. A novel tribometer test setup was used to scan through different materials at different running conditions. Two cylinder liner materials showed significantly lower friction than the other tested materials, CrC–NiCr and MMC. All the thermally sprayed cylinder liners were worn significantly less than the reference material. Based on these results a full-scale single cylinder test was performed to validate the results from the rig. Comparing the thermally sprayed cylinder liner MMC with reference cylinder liner the test showed higher friction torque for the MMC cylinder liner except in one case; at low speed and high pressure. An analysis of the results between the tribometer and the engine points at the importance of the ratio between viscous and mechanical friction losses. The most probable cause of higher friction torque for the thermally sprayed coating (MMC) is that the functional surface of the cylinder liner promotes an increase in viscous friction [79].

Published data on piston ring and cylinder bore wear in engines is very limited because of the technical difficulties involved in performing the measurements. Moreover, cylinder bore wear is more difficult to measure than ring wear because it occurs over a much larger surface area, and the wear rates vary widely at different locations on the bore. In this paper, cylinder liner surface roughness and wear measurements were performed through an experimental study of a single cylinder diesel engine operating at a steady-state. A replication method was used to evaluate wear and surface roughness on a cylinder liner, where measurements were made at different locations on the cylinder liner before and after each test. Replicated surface profiles were measured by a WYKO NT 1100 optical surface profilometer. It was found that surface roughness decreased with time and the rate of decrease was higher during the run-in period. A unique wear volume calculation method that includes bearing ratio parameters was proposed, and reasonable results for wear volume were obtained. Cylinder bore wear rates measured by this replication method were consistent with long-term wear observed in different tests of diesel engines [80].

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Plasma spray coating, hard chrome plating and gas nitriding on cast iron substrate were successfully prepared by three different processes. There are different thermal spray process such as combustion flame spray, high velocity oxy- fuel spray, plasma spraying , vacuum plasma spraying and cold sprays. But the coating produced by plasma arc spray process is widely used in the industries and the process is easy to control. The cast iron substrate was used because the coating after solidification will give the same result as piston cylinder assembly. After preparation of the coating the coating is cleaned. The coating was cut in the form of plate of 90X90X2 mm to control the weight of the disc with in the limit of 120 gram and fixture was designed to fix the plate on the tribometer with the help of screw and nut .There are different wear test such as scratch test, slurry abrasion test, erosion test and **pin on the disc test**. The selection of the wear test depends on the material of the coating and its applications. For marine applications of the coating slurry erosion and corrosion test are commonly perform. But in case of dry applications of the coating the pin on disc and scratch test are commonly perform. For the present study two variables were selected for wear test that was load (30, 40 and 50 N) and wear track (50,60 and 70mm) sliding distance(1.2km) remain fixed during the test. Wear test of the coating was conducted on pin on disc machine under dry conditions. The wear rate was calculated by mass loss methods. The wear disc was weigh before and after the wear test on an electronic balance having least count 0.0001g. The coefficient of friction was found with LVDT which give the frictional force during wear test. The surfaces morphology of worn surfaces of the coating was analysed with scanning electron microscope. The XRD of the worn surfaces was done to determine the change in intermolecular spacing of the worn surfaces of the coating. The wear rate of the coating was found to be increased with increased in load as well as sliding speed. The co-efficient of friction of the coating was found to be decreased with increased load and sliding speed. The d-spacing of the coating molecules on the wear track was found to be decreased with increased in load during the wear test. The microstructure of the worn surfaces of the coating was also examined with optical microscope and no change in microstructure of the coating due to frictional heat was observed. The micro hardness at the cross section of the coating at the wear track was found to be decreased away from the wear track. The main wear mechanism examined by scanning electron was adhesion, deformation and Microcutting.