**LIST OF FIGURE**

|  |  |
| --- | --- |
| **Sr. Number Title** | **Page No.** |
|  **Figure 1.1** Parts of Internal Combustion Engine | 3 |
| **Figure 1.2**. Piston  |  4 |
| **Figure 1.3**. Position of Different Type of Piston Rings on Piston | 6 |
| **Figure 1.4.1.** Trunk Piston | 9 |
| **Figure 1.4.3.** Slipper Piston | 10 |
| **Figure 1.4.4.** Deflector Piston | 11 |
| **Figure 1.4.5.** Steam Piston | 12 |
| **Figure 1.4.6.** Carbon Fiber Composite Component with Thermal Coating | 13 |
| **Figure 1.6.1.** Abrasive Wear | 18 |
| **Figure 1.6.2. Adhesive Wear** | 19 |
| **Figure 1.6.3.** Erosion Wear  | 19 |
| **Figure 3.2.1. Epectromaxx** | 32 |
| **Figure 3.2.2.** Spectromaxx used for Testing | 33 |
| **Figure 3.2.3.** Specimen for Testing & Parent Piston | 34 |
| **Figure 3.2.4.**  Stress Vs Strain Curve | 39 |
| **Figure 3.2.5.** Testing Sample dimension for Tensile Strength | 41 |
| **Figure 3.2.5.1** Testing sample | 42 |
| **Figure 3.3.1.** Wear and Friction Monitor Machine for Pin on Disc test | 47 |
| **Figure 3.3.2.** Anodised Piston Alloy Disc before Wear Test | 48 |
| **Figure 3.3.3.** Tin coated Piston alloy during Wear Test | 49 |
| **Figure 3.4.** Scanning Electron Microscope in DTU, Delhi | 51 |
| **Figure 3.5.** X-Ray Diffractometer in DTU, Delhi | 54 |
| **Figure 3.6.** Vickers Micro Hardness Indentation | 56 |
| **Figure 3.7.** Optical Microscope | 57 |
| **Figure 3.8.1** Nickel Crystal | 59 |
| **Figure 3.8.2.** Nnduction Furnace | 60 |
| **Figure 3.9.1.** Cold Chamber Casting Machine | 62 |
| **Figure 3.11.1.** Piston on Hanger  | 70 |
| **Figure 3.11.2.** Acid Tin Plant | 71 |
| **Figure 3.11.3.** Piston over Acid Tin Bath Tank | 72 |
| **Figure 3.12.1.** Idealized Structure of Anodic Porous Aluminum Oxide  | 74 |
| **Figure 3.12.2.** Cross-section of Porous Oxide in the vicinity of Metal/oxide Interface | 74 |
| **Figure 3.12.3.** Development of Anodized layer from Bare Metal | 75 |
| **Figure 3.12.4.** Hard Anodizing Process | 78 |
| **Figure 3.12.5.** Fixture with Piston in Coating | 79 |
| **Figure 3.12.6** Removed Piston | 80 |
| **Figure 4.1.** Top view of Anodized Coating Surface. | 82 |
| **Figure 4.1.2.** EDS Analysis. | 83 |
| **Figure 4.2.1.** Mass loss of Anodizing Coating with Mild Steel Pin | 85 |
| **Figure 4.2.2**. Wear rate of Anodized Coating w.r.t. time in second at 29.43N load | 86 |
| **Figure 4.2.3.** Wear rate of Anodized coating w.r.t. time in second at 39.24N load.  | 86 |
| **Figure 4.2.2.1** Mass loss of the Anodizing coating with Tungsten Carbide pin at various loading conditions at 90 mm track diameter  | 88 |
| **Figure 4.2.2.2.** Wear rate of Anodized coating w.r.t. time in second at 29.43N load | 88 |
| **Figure 4.2.2.3.** Wear rate of Anodized coating w.r.t. time in second at 39.24N load | 89 |
| **Figure 4.2.2.4.** Wear OF Anodized Disc using Tungsten Carbide. | 90 |
| **Figure 4.2.3.2.** Wear rate of tin coating w.r.t. time in second at 29.43N load | 91 |
| **Figure 4.2.4.1**. Mass loss of the Tin coating with High Carbon Steel Pin Coating at various loading conditions at 60 mm track diameter | 91 |
| **Figure 4.2.4.2.** Wear rate of Tin Coating w.r.t. time in second at 39.24N load with high carbon steel pin | 92 |
| **Figure 4.2.4.3**. Wear rate of Tin Coating w.r.t. time in second at 29.43N load with high carbon steel pin**Figure 4.2.5.1.** Mass loss of the Tin Coating with Mild Steel Pin Coating at various loading conditions at 70 mm track diameter.**Figure-4.2.5.2** Wear rate of Tin Coating w.r.t. time in second at 29.43N load with mild steel pin**Figure-4.2.6.1** Mass loss of the Soft Material with Tungsten Carbide Pin Coating at various loading conditions at 50 mm track diameter**Figure-4.2.6.**2 Wear Rate of Soft Material w.r.t. time in second at 39.24 N load**Figure 4.2.6.2** Wear Rate with Tungsten Carbide pin on Soft Material of Aluminum Silicon Piston Alloy at 29.43N**Figure4.2.7.1** Mass loss of the soft material with high Carbon Steel Pin Coating at various loading conditions at 60 mm track diameter **Figure-4.2.7.2** Wear Rate of soft material w.r.t. time in second at 39.24 N load using high carbon steelpin**Figure-4.2.7.3** Wear Rate of soft material w.r.t. time in second at 29.43 N load using high carbon steel pin**Figure-4.2.8.1** Mass loss of the soft material with mild steel pin coating at various loading conditions at 70 mm track diameter**Figure-4.2.8.2** Wear rate of soft material w.r.t. time in second at 39.24 N load using mild steel pin**Figure-4.2.8.3** Wear rate of soft material w.r.t. time in second at 29.43 N load using mild steel pin**Figure 4.3.1.a.** Variation of coefficient of friction with MS pin W.R.T. Time of anodizing coating**Figure 4.3.1.b.** Variation of coefficient of friction with MS pin W.R.T. Time load 40N of anodizing coating**Figure 4.3.2.a.** Variation of coefficient of friction with WC pin W.R.T. to Time at 29.9 N load of anodizing coating  **Figure 4.3.2.b.** Variation of coefficient of friction with WC pin W.R.T. to Time at 39.24 N load of anodising**Figure 4.3.3.a.** Variation of coefficient of friction with mild steel pin W.R.T. Time at 29.49N of tin coating**Figure 4.3.3.b.** Variation of coefficient of friction with mild steel pin W.R.T. Time at 39.24N**Figure 4.3.4.a**. Variation of coefficient of friction with WC pin W.R.T. Time at 39.24N**Figure 4.3.4.b.** Variation of coefficient of friction with WC pin W.R.T. Time at 29.9N**Figure 4.3.5.A.** Variation of coefficient of friction with HCS pin W.R.T. Time at 39.24N of tin coating**Figure 4.3.6.A.** Variation of coefficient of friction with WC pin W.R.T. Time at 39.24N**Figure 4.3.6.b.** Variation of coefficient of friction with WC pin W.R.T. Time at 29.43N load**Figure 4.3.7.a**. Variation of coefficient of friction with mild steel pin W.R.T. Time at 39.24N**Figure 4.3.7.b.** Variation of coefficient of friction with mild steel pin W.R.T. Time at 29.43N**Figure 4.3.8.a.** Variation of coefficient of friction with HCS pin W.R.T. Time at 29.43N of soft material**Figure 4.3.8.b.** Variation of coefficient of friction with HCS pin W.R.T. Time at 39.24N**Figure 4.4.1.** Indentation over the cross section at a distance of 0.05 micro meters from wear track of without coating at 500 rpm speed and 29.9 N loads (a) with mildsteel pin (b) with high carbon steel pin (c) with Tungsten carbide pin**Figure-4.5.a& b.** Processed image microstructure of aluminum silicon alloy without coating **Figure 4.6.** Worn surface of Tin coating using MS pin, at 500 rpm speed and (a) 29.43 N load (b) 39.24 N load**Figure 4.6.2.1.** Worn surfaces with WC at 500 rpm speed and (a) 29.9 N load (b) 39.24 N load**Figure 4.6.3.1.** Worn surfaces with high carbon steel at 500 rpm speed and (a) 29.9 N load (b) 39.24 N load**Figure 4.6.4.1.** Worn surface with mild steel pin of anodizing coating, at500 rpm speed and (a) 29.9 N load (b) 39.24 N load **Figure 4.6.5.1.** Worn surface withWC pin of anodizing coating, at 500 rpm speed and (a) 29.9 N load (b) 39.24 N load**FIGURE- 4.6.5.1** WEAR SURFACE OF SOFT MATERIAL USING PIN WC, HCS & MILD STEEL **LIST OF TABLES** | 9394 95 95969697 989999100101 102 102 104  104 105 106 107 107 108  109 110 110 111 112 112 114 116 118 119 121 122 122  124   |
| **Sr. Number Title** |  **Page No.** |

|  |  |
| --- | --- |
| **Table 3.1.1**. Variables for Wear Test | 30  |
| **Table 3.1.2.** Design of Experiment Table for Wear Test | 31 |
| **Table 3.2.1.** Composition | 34 |
| **Table 3.2.2.** Hardness  | 45 |
| **Table 3.2.3. Phase of Al-piston Alloys** | 45 |
| **Table 3.11.1 Tin Coating Preparation****Table 3.12.1 Anodising Coating Preparation****Table 4.1 Quantitative table of EDS analysis of aluminium silicon alloy** | 69-7076-7784 |

 **ABBREVIATIONS**

**Symbol Explanation**

µ Co-efficient of Friction

Φ Pin Diameter

g Grams

Kg Kilogram

N Load in Newton

Hv Vickers Microhardness

µm Micrometer

A˚ Armstrong

d Intermolecular distance

θ Angle of incidence

3D Three dimensional

D1, D2 Diagonals of indenter

Rpm Revolution per minute

SEM Scanning electron microscope

XRD X-ray diffractometry

EDS Electronic dispersive spectrometry

ANOVA Analysis of variance