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Experimental Investigation on Improving Life of Spark Plug Using Various Coating

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ABSTRACT- The development of a high performance, long life Spark plug has become essential in response to these demands. While improve performance (high ignitability and low required voltage), the discharge part of the Spark plug needs to be reduced in size. But, in the past this has been difficult because of the limitations in terms of wear. It has been difficult to achieve both smaller discharge parts and longer life. To dramatically improve wear resistance, we researched materials that are both resistant to oxidation and have a high melting point. This research resulted in our development of a various coatings. Through this development we have been able to produce a various coating that surpasses the conventional platinum technology. The coating is now being used in high volume vehicle production. This paper is divided into the following three parts and describes the development of the new generation of coating spark plug.

I. INTRODUCTION

SPARK PLUG

A Spark plug (sometimes, in British English, a sparking plug, and colloquially, a plug) is a device for delivering electric current from an ignition system to the combustion chamber of a spark ignition engine to ignite the compressed air/fuel mixture by an electric spark, while containing combustion pressure within the engine. A spark plug has metal threaded shell, electrically isolated from a central electrode by a porcelain insulator. The central electrode, which may contain a resistor, is connected by a heavily insulated wire to the output terminal of an ignition coil or magneto. The spark plug's metal shell is screwed into the engine's cylinder head and thus electrically grounded. The central electrode protrudes through the porcelain insulator into the combustion chamber, forming one or more spark gaps between the inner end of the central electrode and usually one or more protrusions or structures attached to the inner end of the threaded shell and designated the side, earth or ground electrode. Spark plugs may also be used for other purposes in Saab Direct Ignition when they are not firing, spark plugs are used to measure ionization in the cylinders – this ionic current measurement is used to replace the ordinary cam phase sensor, knock sensor and misfire measurement function. Spark plugs may also be used in other applications such as furnaces wherein a combustible air/fuel mixture must be ignited. In this case, they are sometimes referred to as flame igniters. Spark plugs are under constant chemical, thermal, physical and electrical attack by corrosive gases at 4500 degrees Fahrenheit, crushing pressure of 2000 pounds per square inch (PSI), and electrical discharges up to 18000 volts. This unrelenting assault under the hood of a typical automobile occurs dozens of times per second and over a million times in a day's worth of driving.

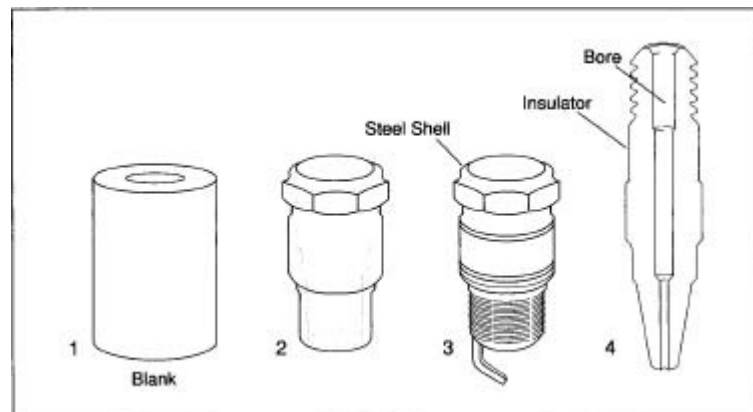
HISTORY OF SPARK PLUG

The spark plug evolved with the internal combustion engine, but the earliest demonstration of the use of an electric spark plug to ignite a fuel-air mixture was in 1777. In that year, Alessandro Volta loaded a toy piston with a mixture of marsh gas and air, corked the muzzle, and ignites the charge with a spark from a Leyden jar. In 1860, French engineer Jean Lenoir created what most closely resembles the spark plug of today.

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Manufacturing of Spark Plug

To make spark plugs, manufacturers first extrude or cold-form steel to the proper hollow shape (1). At this point, the steel forms ore called “blanks”. Next, these blanks undergo further forming operations such as machining and knurling (2), and the side electrode – with only a partial bend is attached (3). The ceramic insulator, with a hollow bore through its center, is molded under pressure (4).

He combined an insulator, electrodes and spark gap in a single unit. As part of his patent application for the internal combustion engine that year, he devoted one sentence to describing the spark plug. He refined this spark plug in 1885.

In the early 1900s, Robert and Frank Stranahan, brothers and partners in an automobile parts importing business, set out to produce a more efficient and durable spark plug. They added gaskets between the metal shell and porcelain insulator, made manufacturing easier, and reduced the possibility of gas leakage past the gaskets. In 1909, Robert Stranahan sold the plug to one automobile manufacturer and went into the spark plug manufacturing business, cornering the market at that time.

The industry exploded as the age of the automobile opened. Eventually, variation in ignition systems, fuel, and performance requirements placed new demands on spark plugs. Although the basic design and function of the plug has changed little since its inception, a staggering variety and number of electrode and insulator materials have been tried.

RAW MATERIALS

The electrodes in a spark plug typically consist of high-nickel alloys, while the insulator is generally made of aluminum oxide ceramic and the shell is made of steel wire.

Selections of materials for both the electrodes and the insulator have consumed much research and development time and cost. One major spark plug manufacturer claims to have tested 2000 electrode materials and over 25000 insulator combinations. As electrodes erode, the gap between them widens and it takes more voltage than the ignition system can provide to fire them. High-nickel alloys have been improved and thicker electrodes have been used to reduce engine performance loss. In addition, precious and exotic metals are increasingly being used by manufacturers. Many modern plugs feature silver, gold and platinum in the electrodes, not to mention center electrodes with copper cores. Silver has superior thermal conductivity over other electrode metals, while platinum has excellent corrosion resistance.

Insulator material also can have a dramatic effect on spark plug performance. Research continues to find a material that better reduces flashover, or electrical leakage, from the plug’s terminal to the shell. The breakthrough use of sillimanite, a material that is found in a natural state and also produced artificially, has been succeeded by the use of more heat resistant aluminum oxide ceramics, the composition of which are manufacturer’s secrets.

One major manufacturer’s process for making the insulator involves wet grinding batches of ceramic pellets in ball mills, under carefully controlled conditions. Definite size and shape of the pellets produce the free flowing substance needed to make a quality insulator. The pellets are obtained through a rigid spray drying operation that removes the water from the ceramic mixture, until it is ready for pouring into molds.

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OPERATION

The plug is connected to the high voltage generated by an ignition coil or magneto. As the electrons flow from the coil, a voltage develops between the central and side electrodes. No current can flow because the fuel and air in the gap is an insulator, but as the voltage rises further, it begins to change the structure of the gases between the electrodes. Once the voltage exceeds the dielectric strength of the gases, the gases become ionized. The ionized gas becomes a conductor and allows electrons to flow across the gap. Spark plugs usually require voltage of 12,000–25,000 volts or more to "fire" properly, although it can go up to 45,000 volts. They supply higher current during the discharge process, resulting in a hotter and longer duration spark.

As the current of electrons surges across the gap, it raises the temperature of the spark channel to 60,000 K. The intense heat in the spark channel causes the ionized gas to expand very quickly, like a small explosion. This is the "click" heard when observing a spark, similar to lightning and thunder.

The heat and pressure force the gases to react with each other, and at the end of the spark event there should be a small ball of fire in the spark gap as the gases burn on their own. The size of this fireball, or kernel, depends on the exact composition of the mixture between the electrodes and the level of combustion chamber turbulence at the time of the spark. A small kernel will make the engine run as though the ignition timing was retarded and a large one as though the timing was advanced.

SPARK PLUG CONSTRUCTION

A spark plug is composed of a shell, insulator and the central conductor. It passes through the wall of the combustion chamber and therefore must also seal the combustion chamber against high pressures and temperatures without deteriorating over long periods of time and extended use.

Spark plugs are specified by size, either thread or nut (often referred to as Euro), sealing type (taper or crush washer), and spark gap. Common thread (nut) sizes in Europe are 10 mm (16 mm), 14 mm (21 mm; sometimes, 16 mm), and 18 mm (24 mm, sometimes, 21 mm). In the United States, common thread (nut) sizes are 10mm (16mm), 12mm (14mm, 16mm or 17.5mm), 14mm (16mm, 20.63mm) and 18mm (20.63mm).

II. LITERATURE REVIEW

H.T. Lin, M.P. Brady, R.K. Richards, D.M. Layton, Characterization of erosion and failure processes of spark plugs after field service in natural gas engines, *Wear*, Volume 259, Issues 7 – 12, July – August 2005, Pages 1063-1067, ISSN 0043-1648: Micro structural and optical spectroscopic analyses were carried out on as-received and used spark plugs after field service in natural gas (NG) reciprocating engines. The objectives of this work was to examine the corrosion and erosion mechanisms of natural gas engine spark plug as well as identify the primary life limiting processes during field operation. The optical emission spectroscopic analysis showed a strong Ca signal in the exposed spark plugs and scanning electron microscopy showed substantial formation of Ca-enriched glassy oxide phase(s) on the electrode surfaces. In addition, intergranular cracking was observed in the subsurface region of both iridium (Ir) and platinum-tungsten (Pt-W) alloy electrode insert tips. The coalescence and subsequent growth of these cracks would accelerate the wear of the electrodes and shorten the lifetime of the spark plugs. Also, extensive internal oxidation and subsequent crack generation occurred along the interface between Ni-base alloy electrode and Pt-W alloy tip insert during field service, which would result in substantial degradation in the ignitability and performance of the electrodes, and thus spark plug failure.

F.A. Soldara, F.T. Mucklich, K. Hrastnik and T. Kaiser, "Description of the discharge process in spark plugs and its correlation with the electrode erosion patterns," in *IEEE Transaction on Vehicular Technology*, vol. 53, no. 4, pp. 1257-1265, July 2004: The phases of the discharges in spark plugs were studied with a high-speed camera and an oscilloscope. The discharges were done using samples of nickel alloys and platinum as cathode in air at pressures ranging from 100 to 900 kPa. For low pressures (100 kPa), a glow discharge occurs after the breakdown. For higher pressures, a discharge follows the breakdown and changes into a glow discharge when the current decreases. The damage produced on the cathode surface was analyzed with scanning electron microscopy and white light interferometry and was correlated with the corresponding discharge. The craters on the surface are mainly produced by the breakdown and arc discharge. The glow discharge delivers energy to the cathode in a large area and produces a negligible material damage. The

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movement of the arc hot spot produces further craters that are commonly overlapped. Transitions from glow to arc, modes produce new small craters, which in some cases can be arranged along polishing traces. This work is relevant for the development of new electrode materials for spark plugs and electrical contacts. **F. Soldera, A. Lasagni, F. Mücklich, T. Kaiser, K. Hrastnik, Determination of the cathode erosion and temperature for the phases of high voltage discharges using FEM simulations, Computational Materials Science, Volume 32, Issue 1, January 2005, pages 123-139, ISSN 0927-0256:** A discharge produces an energy input in the cathode material, which causes the erosion of the material surface. The principal mechanism of erosion is the formation of craters mainly due to melting. From calorimetric results published in the literature, the amounts of energy delivered to the cathode for the different phases of the discharge (breakdown, arc and glow discharge) were calculated. A FEM model was developed to simulate the temperature distribution and the phase transitions, which allows the definition of molten and evaporated zones. These zones were compared with the volumes of craters done in Pt-samples at air with pressures ranging between 1 and 9 bar and static electrode gaps of 2mm. the breakdown energy is enough to melt an amount of material, which is responsible for the formation of very flat craters. The formation of deeper overlapped craters observed in experiments cannot be produced during the breakdown; they are produced by the arc phase of the discharge. The assumption of the crater area as the area for the energy exchange between plasma and material gives the best results in the simulation. The glow discharge produces only a light heating of the cathode, without any significant erosion. **Armando Ortiz, Jorge L. Romero, Ignacio Cueva, Víctor H. Jacobo, Rafael Schouwenaars, Spark plug failure due to a combination of strong magnetic fields and undesirable fuel additives, Case Studies in Engineering Failure Analysis, Volume 1, Issue 2, April 2013, Pages 67-71, ISSN 2213-2902:** Spark plugs designed for optimal durability failed after 100 h of operation. The insulator was covered with a deposit consisting of iron oxides and soot. The strong magnetic field deposits metal ions on the insulator. Organ metallic anti-knocking agents in low-grade fuelacerbate the effect. Government action imposing compliance with fuel composition norms is essential.

III. PROBLEM IDENTIFICATION

Deposits accumulated on the firing end may induce abnormal combustion (pre-ignition), causing problems that include melting of the electrodes.



Fig 3.10 Good

If the edges of electrodes are worn and rounded, sparks will not easily occur, which leads to engine starting problems and mis-firing during running: maximum power cannot be obtained from the engine.



Fig 3.11 Worn Electrodes

Power leaks through the carbon accumulated on the firing end, causing mis-firing as well as hindering engine starting.

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Fig 3.12 Fouled

The deposits accumulated on the spark plug overheat and cause abnormal combustion (pre-ignition) that may lead to melting of the electrodes of the spark plug.



Fig 3.13 Deposits

Why is the firing end appearance of a spark plug important?

Because the firing end appearance reflects the suitability of the spark plug as well as the condition of the engine. There are three basic criteria: good, fouled, and overheated.

The firing end appearance also depends on the spark plug tip temperature. The border-line between the fouling and optimum operating regions (450 degrees Celsius) is called the spark plug self cleaning temperature. It is at this temperature that the deposits accumulated are burnt off.

What is spark plug fouling?

It is a phenomenon by which carbon attached to the firing end causes electrical leakage that leads to mis-firing.

As the high voltage generated by the ignition coil leaks away through the carbon, mis-firing may occur and cause running and starting difficulties.

What is Spark plug overheating?

Prolonged overheating may induce abnormal combustion (pre-ignition), resulting in melting of the spark plug electrodes. Overheated spark plugs have a white insulator surface at the firing end speckled deposits.

Electrode melting represents excessive overheating. When the spark plug temperature exceeds 870°C, the firing end serves as a heat source before sparking and induces abnormal combustion (pre-ignition), possibly damaging the piston.

Causes of overheating and corrective actions

Causes		Corrective actions
Ignition timing too far advanced	==>	Adjustment of ignition timing is required.
Air/fuel mixture(A/F) too lean	==>	Adjustment of air fuel ratio (A/f) is required.
Insufficient cooling water and lubricants	==>	Top up cooling water and lubricants

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Applied turbo boost pressure too high in the case of a turbo engine	==>	Adjustment of turbo boost pressure control is required.
Insufficient tightening of spark plug	==>	Tighten to specified torque
Use of too hot a spark plug	==>	Use colder spark plug (Example: BK R5E-11 --> BK R6E-11)

Table 3.2 Causes of overheating and Corrective actions.

What is lead fouling?

Lead deposits accumulated on the spark plug firing end help electricity to leak away and result in mis-firing.

When the lead contained in gasoline as an octane enhancer, adheres as the firing end of the spark plug, the high voltage generated by the ignition leaks through the lead deposits and causes mis-firing during acceleration. This problem often takes 2,000 - 3,000 km (1,200 - 1,800 miles) to become apparent.

3.1 INSULATION RESISTANCE OF SPARK PLUG VS VEHICLE SPEED.

Lead fouling does not appear during starting or low speed running. On the other hand, mis-firing occurs when accelerating from the middle speed range since the insulation resistance of the spark plug drops quickly.

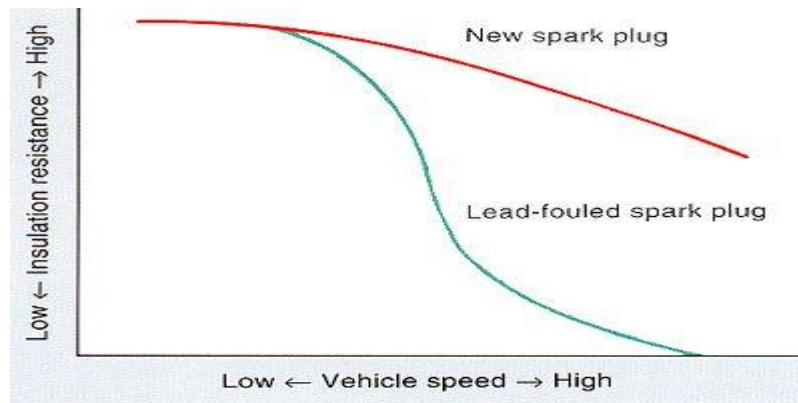


Fig 3.14 Insulation resistance of a spark plug vs. vehicle speed.

IV. METHODOLOGY

SPARK PLUG CLEANING

Firstly done, your safety gear: this includes safety glasses and gloves. Place your spark plug in a vice with the electrode facing up toward you. Grab a wire brush, and then brush the spark plug around the electrode to remove carbon build up. Once the spark plug has been wire brushed much of the carbon on it will have been removed. Take a piece of 220 emery paper. Place the emery paper between the two electrodes. Move the paper side to side against the top hooked electrode. Turn the paper over and clean the bottom electrode in the same manner. Using a can of compressed air or an air hose blow the dust and debris off the spark plug. This allows a maximum connection between the two electrodes. Now the gap between the two electrodes needs to be measured. Use a Feeler Gauge to accomplish this. Each plug has specific gap measurement choose the appropriate gauge size. It should slide between the electrodes with minimal resistance.

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V. PURPOSES OF A COATING

A coating serves many purposes. Some of these are presented as below:-

Protection of steel structures from the environment by acting as a barrier between the substrate and the aggressive environment, such as the marine and industrial environments. Control of solvent losses. Control of marine fouling; certain constituents in coating control the growth of mildew and marine fouling in seawater. Reduction in friction (coating reduces friction between two contacting surfaces). Pleasant appearance; certain types of coatings provide a pleasant appearance and produce attractive surroundings. Change in light intensity; by selection of appropriate coatings the light intensity in rooms and buildings can be varied as desired. Visibility; many combinations of colors because of their visibility from large distances are used on television and radio towers to warn aircraft. Modification of chemical, mechanical, thermal, electronic and optical properties of materials. Application of thin coatings on low-cost substrates results in increased efficiency and cost savings.

5.3 PVD COATING PROCESS

Physical vapor deposition (PVD) is fundamentally a vaporization coating technique, involving transfer of material on an atomic level. It is an alternative process to electroplating

The process is similar to chemical vapor deposition (CVD) except that the raw materials/precursors, i.e. the material that is going to be deposited starts out in solid form.

PVD processes are carried out under vacuum conditions. The process involved four steps:

- Evaporation
- Transportation
- Reaction
- Deposition

Evaporation

During this stage, a target, consisting of the material to be deposited is bombarded by a high energy source such as a beam of electrons or ions. This dislodges atoms from the surface of the target, 'vaporizing' them. Stage For the above examples, the reactive gases may be oxygen, nitrogen and methane.

Transport

This process simply consists of the movement of 'vaporized' atoms from the target to the substrate to be coated and will generally be a straight line affair.

Reaction

In some cases coatings will consist of metal oxides, nitrides, carbides and other such materials. In these cases, the target will consist of the metal. The atoms of metal will then react with the appropriate gas during the transport stage. For the above examples, the reactive gases may be oxygen, nitrogen and methane. In instances where the coating consists of the target material alone, this step would not be part of the process.

Deposition

This is the process of coating build up on the substrate surface. Depending on the actual process, some reactions between target materials and the reactive gases may also take place at the substrate surface simultaneously with the deposition process.

PHOTOCOPY



Fig 5.3 Zinc Coated Spark Plug



Fig 5.4 Nickel Coated spark plug

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Fig 5.5 Chromium Coated Spark Plug

VI. RESULT AND DISCUSSION

CARBON DEPOSITION TEST

Carbon removal specifically formulated for removal of completely carbon, grease, oil, varnishes and other heavy deposits from petrol engine. Its unique combination effectively remove carbon deposits, varnish, gummy matter, baked/burnt on grease deposits and all persistent with high solvency and penetrating capabilities to remove carbonaceous residue formed by fuel engine part. RXSOL-16-1003-025 is a highly concentrated wetting emulsifying agent which makes this protect water soluble.

This powerful action is based on two layer mechanism. The top layer prevents the evaporation of the volatile components in the bottom layer. The bottom layer removes the deposited substances. This way, the deposits are bind and trapped resulting to complete and safe removal. Carbon cleaner is very active which eliminates the need for scrubbing or brushing which can cause mechanical damages to disc and result in poor performances.

As per ASTM E384 and IS/BS Standards

CARBON DEPOSITION IN PERCENTAGE %	
MILD STEEL	80%
NICKEL	76%
CHROMIUM	72%
ZINC	63%

Table 6.1 Carbon deposition Test

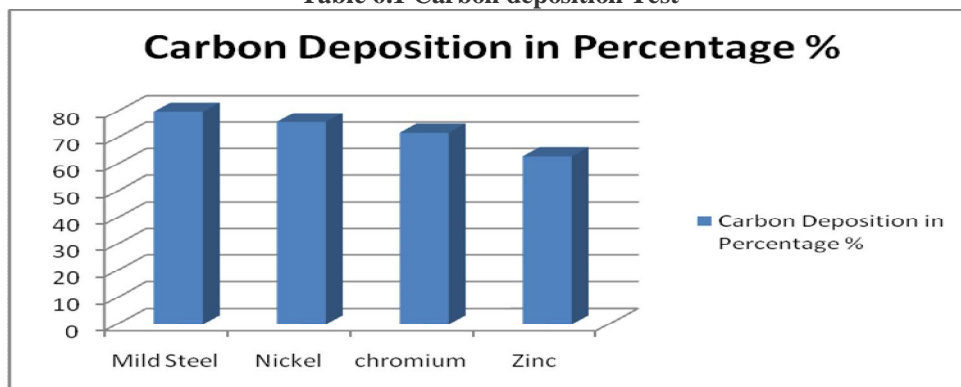


Fig 6.1 Carbon deposition

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6.2 KNOOP HARDNESS TEST

The Knoop hardness test is a microhardness test - a test for mechanical hardness used particularly for very brittle materials or thin sheets, where only a small indentation may be made for testing purpose. A pyramid diamond point is pressed into the polished surface of the test material with a known (often 100g) Load, for a specified dwell time, and the resulting indentation is measured using a microscope.

As per ASTM E384 and IS/BS Standards

WORK PIECE MATERIAL	SURFACE TREATMENT	KNOOP HARDNESS	THICKNESS IN μm
MS	-	210	-
MS	ZINC	433	25
MS	CHROMIUM	525	30
MS	NICKEL	735	40

Table 6.2 Knoop hardness Test

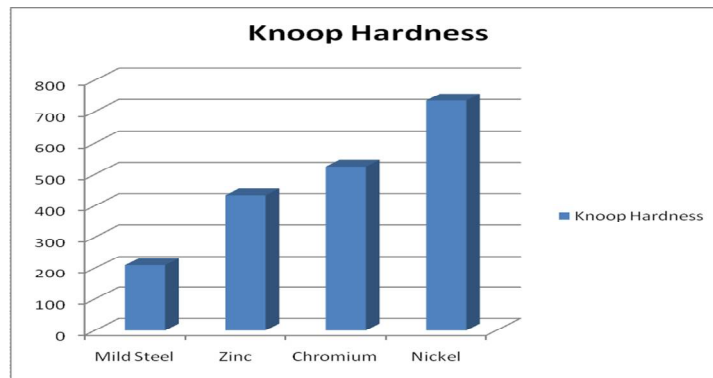


Fig 6.2 Knoop Hardness

6.3 CORROSION TEST

Cyclic corrosion testing (CCT) has evolved in recent years, largely within the automotive industry, as a way of accelerating real world corrosion failures, under laboratory controlled condition. As the name implies, the test comprises different climates which are cycled automatically. So the samples under test undergo the same sort of changing environment that would be encountered in the natural world. The intention being to bring about the type of failure that might occur naturally, but more quickly, i.e. accelerated. By doing this manufacturers and suppliers can predict more accurately, the service life expectancy of their products.

6.3.1 Percentage of Petroleum 6.2

SL NO	MATERIALS	330K	550K	600K
1	CHROMIUM	16.70 g/cm^2	31.23 g/cm^2	35.96 g/cm^2
2	ZINC	18.99 g/cm^2	33.21 g/cm^2	37.35 g/cm^2
3	NICKEL	15.90 g/cm^2	28.21 g/cm^2	33.42 g/cm^2

Table 6.3 Corrosion Test (% of Petroleum is 6.2)

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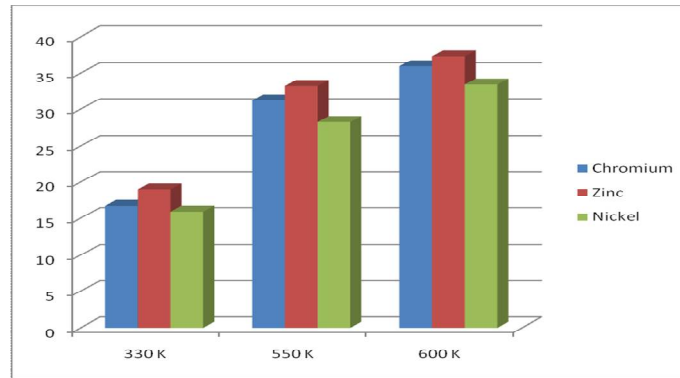


Fig 6.3 Corrosion Test (% of Petroleum 6.2)

6.3.2 Percentage of Petroleum 8.2

SL NO	MATERIALS	330K	550K	600K
1	CHROMIUM	18.95 g/cm ²	32.49 g/cm ²	42.80 g/cm ²
2	ZINC	20.92 g/cm ²	34.37 g/cm ²	44.61 g/cm ²
3	NICKEL	17.20 g/cm ²	30.15 g/cm ²	40.10 g/cm ²

Table 6.4 Corrosion Test (% of Petroleum is 8.2)

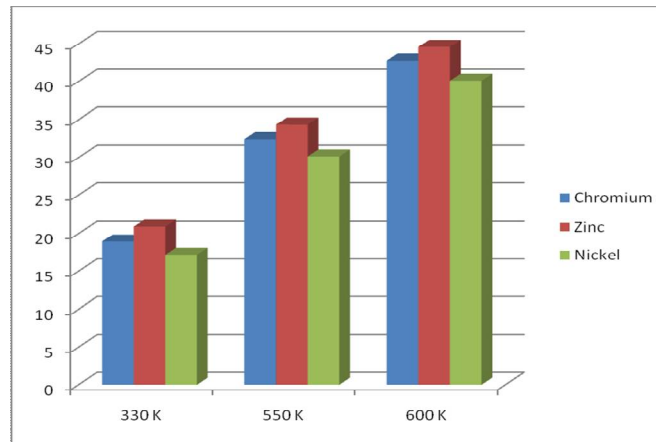


Fig 6.4 Corrosion Test (% of Petroleum 8.2)

6.3.3 Percentage of Petroleum 10

SL NO	MATERIALS	330K	550K	600K
1	CHROMIUM	20.09 g/cm ²	38.55 g/cm ²	46.57 g/cm ²
2	ZINC	22.82 g/cm ²	40.68 g/cm ²	48.91 g/cm ²
3	NICKEL	18.26 g/cm ²	36.27 g/cm ²	44.85 g/cm ²

Table 6.5 Corrosion Test (% of Petroleum is 10)

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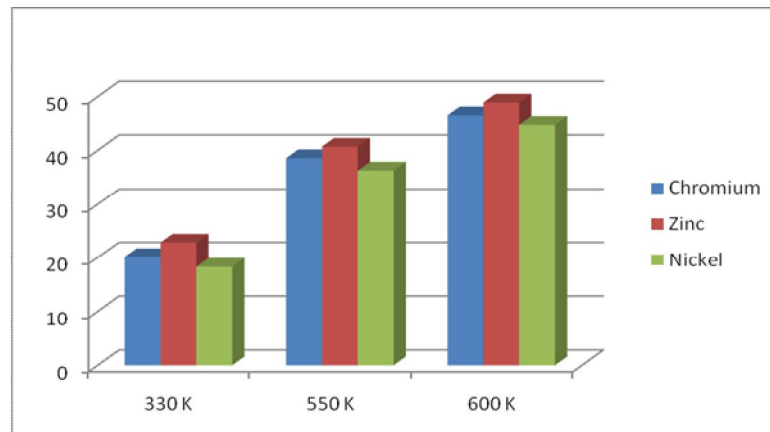


Fig 6.5 Corrosion Test (% of Petroleum 10)

VII. CONCLUSION

Proper electro deposition of mild steel using zinc, Chromium and Nickel particle was carried out. The Carbon Deposition, Knoop Hardness and Corrosion Test of the resultant deposition were investigated with the following deductions:

- Increasing of Chromium percentage causes decreasing the Corrosion.
 - By using Nickel, Zinc and Chromium the hardness of the ground electrode gets increased.
 - Zinc and Chromium is used to resists the corrosion in spark plug
 - By coating the Zinc, Nickel and Chromium, the deposition of Carbon content gets decreased.
 - Due to this Coating the Environmental Pollution gets decreased.
 - Performance of engine also improved.
- Ignition takes place in correct time

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