Synthesis of Electroless Ni-P-C_g (graphite)-SiC Composite Coating on Piston Rings of a Small Two Stroke Utility Engine

by

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Thesis submitted in fulfillment of the requirements
for the degree of
Doctor of Philosophy

February 2011

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ACKNOWLEDGEMENTS

First and foremost, all profusely deep thank to the Almighty Allah SWT, The Generous, for guiding me all the way and for endowing me with plentiful gifts.

I wish to express my deepest gratitude to my main supervisor, Assoc. Prof. Dr. Zaidi Mohd. Ripin (Dean of School of Mechanical Engineering), and co-supervisor Prof. Dr. Hj. Zainal Arifin Hj. Ahmad, for accepting me as one of their Ph.D students. Their advices, criticisms and encouragement guided me to discover and investigate the heart of research. I must offer thanks to them for their time and patiently listening throughout this research.

Sincere appreciation and gratitude is addressed to Prof. Dr. Horizon Gitano-Briggs. And my great thanks to Assoc. Prof. Dr. Esmat Hj. Khalid (President of Duhok University, Iraq) for his help and support. I would like to extend my appreciation to the respective lecturers, staff and technicians of schools of Mechanical and Material Engineering, especially to Assoc. Prof. Dr. Hj. Zainal Alimuddin B. Zainal Alimuddin. My gratitude also goes to the technicians of Scanning Electron Microscopy (SEM), School of Materials and Mineral Resources Engineering, USM, who helped me so much. Special thank goes to special friend Soran and to all friends and colleagues in Ph.D room for their kindness and cheerful conversations. Your smiles always make me feel that I am at home and give me the motive action to continue.

Sincerely, I would like to dedicate this Ph.D thesis to my wife, son, and daughters as a gratitude for their sacrifices.

My heart felt thanks go to my dear brothers, Hj. Azad, Hj. Shorish, and Hj. Darbaz. To you I owe a great debt of gratitude for your trust, friendship and encouragement. You gave me confidence and make me believe in future. To my sister, Naznaz for surrounding me with care.

To my teachers in Iraq, thousand thanks for your unforgettable brilliant teaching. To my faithful friends in Kurdistan, Dr. Salih Al-atrushy, and Mr. Muhammad Esmat. Really no words can express my appreciation to you. Your continuous moral support pushed me always to do the best.

To those that I might have forgotten to mention, I owe you my deepest thanks and be assure that my gratitude is not less than for those listed above.

FARHAD BILAL BAHAAIDEEN
February 2011

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LIST OF ABBREVIATION

ASM	:	American Society of Metals
ASTM	:	American Standards for Testing of Materials
Ni-P	:	Nickel-Phosphorus
C_g	:	Graphite
SiC	:	Silicon carbide
DC	:	Direct current
EDX	:	Energy Dispersive X-ray Spectroscopy
FESEM	:	Field Emission Scanning Electron Microscopy
nm	:	nanometer
SEM	:	Scanning Electron Microscope
wt.%	:	Weight percentage
XRD	:	X-ray diffraction
μm	:	micrometer

Sintesis Elektrosaduran Komposit Salutan Ni-P-Cg(graphit)-SiC
Pada Gelang Piston Enjin Dua Lejang

ABSTRAK

Kajian mengenai elektrosaduran ke atas substrat gegelang piston sebenar sebuah enjin kecil dua lejang telah dilakukan. Substrat telah dielektrosadur dengan Ni tulen, Ni-SiC, Ni-C_g(grafit)-SiC dan Ni-P-C_g(grafit)-SiC. Suhu saduran ditetapkan pada suhu bilik, nilai pH dilaraskan dari 3.6 ke 4.0 dan ketumpatan arus ditetapkan pada 30 mA/cm^2. Sebagai perbandingan, saduran tanpa elektrik untuk Ni-P-C_g(grafit)-SiC juga dilakukan pada 90 °C. Kesan proses sepuhlindap pada 400°C selama satu jam untuk kedua-dua sampel elektrosaduran dan saduran tanpa elektrik juga dilakukan. Keratan rentas semua sampel termasuk sampel tanpa saduran telah dikaji dan dianalisa menggunakan Mikroskop Elektron Imbasan (FESEM), EDAX dan mikrokekerasan. Mikrograf menunjukkan bahawa keadaan partikel-partikel C_g dan SiC yang terbenam di dalam matrik Ni tertabur secara seragam hasil daripada tindakan adukan mekanikal. Kekerasan mikro untuk sampel tidak disadur ialah 283 Hv dan telah meningkat ke 404 Hv selepas dielektrosadur dengan Ni-P-C_g(grafit)-SiC. Walau bagaimanapun, mikrokekerasannya meningkat ke 844 Hv selepas di sepuhlindap pada 400°C selama satu jam. Mikrokekerasan untuk sampel yang dilakukan saduran tanpa elektrik telah meningkat ke kekerasan lebih tinggi iaitu 851 Hv. Adalah didapati bahawa purata kekasaran permukaan untuk gegelang piston tidak disadur bertambah baik dari 1.095 µm ke 0.900 µm dan keadaan ini telah merendahkan pekali geseran iaitu 0.18 berbanding 0.23 apabila disadur dengan Ni-P-C_g(grafit)-SiC.

Synthesis of Electroless Ni-P-C_g (graphite)-SiC Composite Coating on Piston Rings of a Small Two Stroke Utility Engine

ABSTRACT

Electroplating of piston rings substrate of a small two stroke utility engine was carried out. The substrates were electroplated with pure Ni, Ni-SiC, Ni-C_g(graphite)-SiC, and Ni-P-C_g(graphite)-SiC. The plating temperature was fixed at room temperature, pH was regulated from 3.6 to 4.0, and current density was fixed at 30 mA/cm^2. For comparison, Ni-P-C_g(graphite)-SiC electroless plating was also studied at 90 °C. The effect of annealing process at 400°C for one hour was also studied for both electroplating and electroless plating of Ni-P-C_g(graphite)-SiC samples. Cross-sections of all samples, including of the uncoated, were studied and analyzed using Field Emission Electron Microscope (FESEM), EDAX, and microhardness. The micrographs showed that the C_g and SiC particles were co-deposited. The coating shows a compact embedding of C_g and SiC particles in the Ni matrix, uniformly and largely distributed in the coating by virtue of mechanical stirring. The microhardness of the uncoated sample was 283 Hv and has been improved to 404 Hv after electroplated with Ni-P-C_g(graphite)-SiC. However, the microhardness has further improved to 844 Hv after annealing at 400°C for one hour. The microhardness of the annealed electroless plated Ni-P-C_g(graphite)-SiC produced even higher hardness at 851 Hv. It was found that the average surface roughness of an uncoated piston ring has improved from 1.095 µm to 0.900 µm and lower friction coefficient of 0.18 compared to 0.23, after Ni-P-Cg (graphite)-SiC composite coating.

CHAPTER 1

INTRODUCTION

1.1 General

Small two stroke utility engines provide compact and lightweight source of power. Due to its advantages of mechanical simplicity, having no valves and ability to generate power on every crank revolution its application is worldwide. In Asia alone for example there are over 50 million 2-stroke cycle engine powering mostly small displacement motorcycles [Nathan et al., 2005], however, they suffer from poor fuel economy and high levels of emissions. To meet more demanding fuel economy and emission standards, new challenges in engine design include reduced friction and wear. The friction loss is the most important factor in determining the fuel economy and performance of the vehicle utilizing the power of the engine. Piston-ring pack rubbing is responsible for the majority of the frictional losses in small two stroke utility engines. Approximately 53% of the friction losses are due to the piston- cylinder system [Ripin et al., 2007], of which 70–80% comes from the piston rings [Ryk and Etsion, 2006]. Mechanical friction can be reduced by improving design of rubbing and sliding surfaces or by using the right materials for coating.

Composite coatings make a new class of materials which are mostly used for mechanical and tribological applications. Ever since the first development of composite materials, the goal has been to achieve a combination of properties not achievable by any of the elemental materials acting alone. A combination of dissimilar materials could produce a composite solid with wide mechanical and tribological properties. However, these properties depend upon the contribution from the distributed and the matrix phases of a composite material. There are a number of methods to prepare the particle-dispersed metal matrix composites [Narayan and Chattopadhyay, 1982]. However, the most common method is composite plating. The incorporation of particles into a metal matrix by this method is based on the electroplating- [Dennis and Such, 1986] and electroless [Mallory and Hajdu, 1990] plating techniques. However, among many methods of preparing dispersion-hardened alloys, electroless deposition is an economic and suitable method of producing composite coatings.

Electroplating is one of the popular and well-studied surface engineering techniques used for corrosion protection in many industries. Electroplating can be defined as the deposit of a very thin layer of metal electrolytically to a base metal (Niranatlumpong and Koipraserta, 2006). The object that is to be plated is immersed into the plating bath and a low voltage D.C. current is applied to the bath. Since electrical current flows from positive to negative, the positively charged ions at the anodes flow through the plating bath's metal electrolyte toward the negatively charged cathode. This movement causes the metal ions in the bath to migrate toward extra electrons located at the cathode's surface outer layer. By means of electrolysis, the metal ions are taken out of solution and are deposited as a thin layer onto the surface of the object. This process is called electrode position (Durney, 1984).

Electroless plating, also known as chemical plating, it involves several simultaneous reactions in a bath plating solution, which occur without the use of external electrical power. The reaction is accomplished when hydrogen is released by a reducing agent, normally sodium hypophosphite, and oxidized thus producing a negative charge on the surface of the part.

Metal finishing is the name given to a wide range of process carried out in order to modify the surface properties of a metal, e.g. by the deposition of a layer of another metal alloy, composite, or by formation of an oxide film. The origins of the industry lay in the desire to enhance the value of metal articles by improving their appearance, but in modern times the importance of metal finishing for purely decorative reason has decreased. The trend is now towards surface treatment which will impart corrosion resistance or particular physical or mechanical properties to the surface (e.g. electrical conductivity, heat or wear resistance, lubrication or solderability) and hence, to make possible the use of cheaper substrate metals or plastics covered to give them essential metallic surface properties. It should be emphasized that not all surface finishing is carried out using electro and electroless chemical methods, but electro and electroless plating still represents a large portion of the metal finishing industry.

The objective of an electroplating and electroless plating process is to prepare a uniform deposit which adheres well to the substrates and which has the required mechanical, chemical and physical properties. Moreover, it is of overriding importance that the deposit properties meet their specification on all occasions, i.e. the process is both predictable and reproducible. On the other hand, many metals may (by modification of the bath and electro and electroless plating conditions) be deposited with different properties. It is for this reason that it is not possible to define a single set of conditions for electro and electroless plating of each metal; the bath, current density, temperature, etc., these will depend to some extent on the deposit properties required.

It is important that the plating bath is stable for a long period of time because of the importance of the reproducibility of the deposit. It is also necessary that the quality of deposit is maintained over a range of operating conditions, since some variations in concentrations and current density are bound to occur, particularly when different objects are to be plated. Lee et al., (2007) reported that the electroless deposition of nano-sized particles is more difficult than of macro-sized particles and showed a rougher plated surface compared to the micro-sized particles, which may be attributable to the agglomeration of nano-sized particles in the plating bath. Huang, (2003) discussed the

microstructure and properties of Ni–P–PTFE–SiC. Additionally, Osiewicz et al., (1999) reported the phase composition and surface morphology of an electrolytic Ni– P–TiO2–PTFE composite for an electrochemical reaction electrode. Zhen-Yan et al., (1998) submitted electrodeposited Re–Ni–W–SiC–PTFE composite and their properties. Recently, in order to improve the physical and mechanical properties of coatings, many kinds of composite coatings based on nickel were developed using the electrodeposition method such as Ni/SiC [Lee et al., 2007], Ni/ZrO2 [Hou et al., 2006], Ni/Al2O3 [Dong et al., 2006], Ni/WC [Surender et al., 2004] and Ni/B [Krishnaveni et al., 2006]. Among these materials, nickel deposits with incorporation of hard and lubricating particles such as SiC & Cg, combine anti-corrosion properties (due to the presence of nickel), with mechanical and tribological performances (due to the presence of particles of SiC & Cg). It is known that electroless Ni–P coating has a high plating capability, high bonding strength, excellent weldability and good antiwar. Cg can keep the constant friction coefficient under high temperature and high sliding velocity because it is insensitive to temperature [Zhang and Zhou, 1993]. SiC particle has many superior properties, such as low price, good chemical stability, high microhardness and wear resistance at high-temperatures.

Therefore, as a second phase to strength composite materials, SiC is an economic and powerful material. Various properties depending on both the electro and electroless plating techniques and hard particle addition are taken into account.

An experimental study was performed on piston rings of a small two stroke utility engine, because piston-ring pack rubbing is responsible for the majority of the frictional losses in small two stroke utility engines. Approximately 53% of the friction losses are due to the piston-cylinder system [Ripin et al., 2007], of which 70–80% comes from the piston rings [Ryk and Etsion, 2006]. Mechanical friction can be reduced by improving design of rubbing and sliding surfaces or by using the right materials for coating. It is also to prepare alloy plating for automotive application (end user), because alloy plating is much more difficult to be implemented on piston ring rather than on specimen plate. Also to do a real test on the small two stroke utility engine, the coated and uncoated piston rings operated at various speeds for comparison study and improvement.

Different types of composite coatings, including pure Ni, Ni-SiC, Ni-Cg-SiC, Ni-P-Cg-SiC, and electroless Ni-P-Cg-SiC composite coatings are compared with non- coated piston rings. From the experimental procedures implemented in this work, electro and electroless Ni-P-Cg-SiC composite coating onto piston rings was successfully co-deposited with excellent homogeneity at all over the actual standard piston rings surfaces. It was also found that the electro and electroless Ni-P-Cg-SiC composite coating onto actual piston rings significantly exhibited excellent high hardness, low friction coefficient and low roughness.

1.2 Problem statement

Small two stroke utility engines are well known for their poor emissions and fuel consumption characteristics. Their low cost and light weight, however, continue their popularity for hand held power applications. As mentioned previously, to meet more demanding fuel economy and emission standards, new challenges in engine design include reduced friction. The friction loss is the most important factor in determining the fuel economy and performance of the vehicle utilizing the power of the engine. Piston-ring pack rubbing is responsible for the majority of the frictional losses in small two stroke utility engines. Mechanical friction can be reduced by improving design of rubbing and sliding surfaces or by using the right materials for coating. The metal matrix composites containing ceramic particles as a distributed phase are useful in a lot of applications especially in the field of engineering as anti- wear and anti-frictional materials [Straffelini et al., 1999]. Furthermore, the mechanical and tribological properties of Ni coating can be improved by the incorporation of different solid particles which are categorized as hard and lubricating [Grosjean et al., 2001]. However, the coating hardness decreases correspondingly with the volume fraction of lubricating particles in the coating, and the friction coefficient becomes worse because of the hard particles. To solve the above problem, complex composite coatings containing both hard and lubricating particles are receiving increased interest. In order to improve the physical and mechanical properties of coatings, many kinds of composite coatings based on nickel were developed by electro and electroless deposition methods. In coating, the aggregate particles are held or linked together by a hardened composite coating. Therefore, the coating and particle properties are interconnected to each other. To determine the features of coating properties, it is necessary to know the features of the hard particle addition. Therefore, in order to get more understanding on the effects of different particles in coating, investigation on the characteristics of the hard particles addition are necessary. It is known that graphite (Cg) is a frequently used solid lubricant material and SiC particle has many superior properties, such as good chemical stability high microhardness and wear resistance at high- temperatures.

There are many researches, but from previous studies and through experimental investigations it decided to combine all materials (Ni-P-Cg-SiC) together with new different compositions, new different particles size (i.e. Cg & SiC), and new electro-electroless plating conditions to get most properties (i.e., produce a composite coating with wide mechanical and terminological properties), like high hardness, low friction coefficient, and low surface roughness

In order to increase the hardness of actual standard piston rings and reduce friction coefficient, roughness, fuel consumption, emission, and improve the efficiency of such hand held two-stroke engines, it has been chosen to focus on fabrication and characterization of different new tribological coatings and their applications onto actual piston rings of a small two stroke utility engine.

1.3 Objective of the study

This research deals with the effects of fabrication of pure Ni, Ni-SiC, Ni-Cg(graphite)-SiC, and Ni-P-Cg(graphite)-SiC composite coating via electroplating and synthesis of electroless Ni-P-Cg(graphite)-SiC composite coating on piston rings and their influence on the properties of piston rings of a small two stroke utility engine.

The objectives of the research are:

1. To fabricate, and test of different composite coatings (pure Ni, Ni-SiC, Ni-Cg(graphite)-SiC, and Ni-P-Cg(graphite)-SiC) on piston rings via electroplating and determine the optimum level of microhardness improvement of piston rings.
2. To compare the properties of Ni-P-Cg(graphite)-SiC composite coating synthesized by electroplating with electroless processes in terms of the following parameters:
    a) Microhardness.
    b) Tribological properties (friction coefficient and surface roughness).
    c) Annealing states

1.4 Scope of research

The scope of research is divided into three parts:

1. Preparation and characterization of chemicals, raw materials, selection of plating bath composition, finding out the electro and electroless plating conditions that are suitable for fabricating of individual composite coating, and preparation of piston rings substrate.

2. Fabrication and characterization of pure Ni, Ni-SiC, Ni-Cg(graphite)-SiC, and Ni-P-Cg(graphite)-SiC composite coatings via electroplating and its application onto piston rings, involving determination of Cg(graphite) and SiC particles in the coating, their distribution, microstructure, thickness, microhardness and comparison study of the surface properties of coated piston rings with uncoated piston rings.

3. Synthesis and characterization of electro and electroless Ni-P-Cg (graphite)- SiC composite coating and its application onto piston rings of a small two stroke utility engine, involving determination of Cg(graphite) and SiC particles in the coating, their distribution, microstructure, thickness, roughness, friction coefficient, and comparison study of the surface properties of coated piston rings with uncoated piston rings.

1.5 Summary

An experimental study was performed on actual piston rings of a small two stroke utility engine. Various properties depending on both the electro and electroless plating techniques and hard particles addition are taken into account. After fabrication of different types of composite coatings, which they were included electroplating pure Ni, Ni-SiC, Ni-Cg-SiC, Ni-P-Cg-SiC and electroless Ni-P-Cg-SiC composite coatings and their applications onto actual piston ring's substrate of a small two stroke utility engine, a comparison study were made between the performance of different composite coatings onto actual piston rings with uncoated piston rings. From the experimental procedures implemented in this work, electro and electroless Ni-P-Cg-SiC composite coating onto actual piston rings was successfully co-deposited with excellent homogeneity at all over the actual standard piston rings surfaces. Therefore, fabrication of new tribological coating such as Ni–P–Cg–SiC composite coating and its application onto actual piston rings of small two stroke utility engine is to increase hardness, reduce friction coefficient, and reduce surface roughness.

CHAPTER 2

LITERATURE REVIEWS

2.1 Introduction

This chapter describes the introduction of coating, coating components and coating materials, why these materials are used in composite coating, and how they affect the mechanical and tribological properties of coating. The study also focused on the previous results and evolutions of four principal parameters for coatings, characterizing the performance of high hardness, low friction coatings (coefficient of friction), low roughness, and the relative thickness of coatings. There are various types of coating materials but only nickel, phosphorous, graphite, and silicone carbide are reviewed in detail.

2.1.1 Literature survey of composite coating

Composite plating is widely used for production of new materials that require specific mechanical, chemical and physical properties. This technique has demonstrated to be very convenient because of its simplicity and low cost in comparison with other methods such as sputtering and vapor deposition.

Coating is increasingly being used to improve the tribological performance of machine elements such as sliding bearings, seals and valves. In the development of modern materials, functionality is often improved by combining materials of different properties into composites. Many classes of composites exist, most of which address improved mechanical properties such as stiffness, strength, toughness, and resistance to fatigue. Coating composites (i.e., surface-engineered materials) are designed to specifically improve functions such as tribological, electrical, optical, electronic, chemical, and magnetic. It is thus natural to select the bulk of component to meet the demands for stiffness, strength, formability, cost, etc., and then modify or add another material as a thin surface layer, which is the location of virtually all other functional properties. Application of coatings on machine elements is therefore a very efficient way of improving their friction and wear resistance properties [Bharart, 2000]. Aluminum and its alloys are used extensively in automotive industries because of their low density and high strength to weight ratio [Bakes, 1979]. However, poor resistance to wear and erosion are serious concern for prolonged use [Wan and Xue, 1996]. Metal matrix composites are a new class of materials that exhibit good wear and erosion resistance properties, higher stiffness and hardness at a lower density as compared to the matrix [Sheng- Chang & Wen-Cheng, 2003]. However, the presence of the ceramic particles in the metallic matrix makes the matrix brittle [Clyne and Withers, 1993]. In this regard, it may however be noted that wear is a surface dependent degradation mode, which may be improved by a suitable modification of surface microstructure and/or composition [Rabinowicz, 1965]. Hence, instead of bulk reinforcement, if the ceramic particles would be added to the surface, it could improve the wear and erosion resistance without sacrificing the bulk properties. Dispersion of ceramic particles on metallic substrate surface and the control of its distribution are difficult to achieve by conventional surface treatments [Budinski, 1988].

Nickel electroplating is a commercially important and versatile surface finishing process. It is used for decorative, engineering and electroforming purposes because the appearance and other properties of electrodeposited nickel can be varied over wide ranges by controlling the composition and the operating parameters of the plating solution [Schlesinger and Paunovic, 2000].

Electroless nickel and electroless composite coating with graphite (Cg) and/or SiC particles were deposited by electroless plating. The micrograph of different coatings was conducted with scanning electron microscopy (SEM). X-ray diffraction (XRD) and differential scanning calorimetry (DSC) was used to analyse the microstructure and study the phase transition of the coatings during the heat treatment [Wu et al., 2006]. The tribological behaviour and wear mechanism of Ni–P–Gr (graphite)–SiC (manufactured by electroless plating) is surveyed in this paper.The worn surface, wear debris and the compositional changes that take place during wear were characterized using scanning electron microscopy (SEM) and energy-dispersive analysis of X-ray (EDAX).The wear rate of the composite decreased with an increase in microhardness [Wu et.. al, 2006]. Ni–SiC nanocomposite coatings were produced by electrodeposition from a nickel sulfate bath containing SiC nanoparticles with an average particle size of 30 nm. The characteristics of the coatings were assessed by scanning electron microscopy and microhardness test. The friction and wear performance of Ni–SiC nanocomposite coatings and Ni film were comparatively investigated sliding against Si_3N_4 ceramic balls under nonlubricated conditions. The results indicated that compared to Ni film, Ni–SiC nanocomposite coating exhibited enhanced microhardness and wear resistance [Zhou et al., 2007]. This keynote address will provide a comprehensive overview of various lubrication aspects of a typical powertrain system including the engine, transmission, driveline, and other components, as well as the integration of these lubrication and surface engineering concepts into a unified automotive power train system. In addition, this presentation will focus on the current status and future trends in automotive lubricants including discussion of current and anticipated future requirements of automotive engine oils [Simon et al., 2004]. Surface treatments used in daily manufacturing of parts for the automotive industry are selected to serve functional and decorative requirements achieved by mass production. Increased loads (mechanical, thermal, etc.), longer lifetime, weight reduction, friction reduction, and corrosion resistance are demanded for modern automotive systems [Vetter et al., 2006]. Nickel composite coatings have been prepared on mild steel substrates by sediment electro-co-deposition (SECD) technique. Silicon nitride, fly ash and calcium fluoride are used as the reinforcements. Metallographic studies, microhardness, friction and wear tests under various loads and sliding speeds have been carried out on these coatings. Optical and scanning electron microscopy (SEM) studies on the worn surfaces were conducted. A theoretical model was used to predict the wear rates of the composite coatings [Ramesha and Ramesha, 2003]. Micron and submicron-sized SiC-particles (5 and 0.3 μm, respectively) were codeposited with nickel from a Watts electrolyte. The Ni–SiC composite coatings showed a better corrosion resistance in a 0.6 M NaCl solution than nickel electrodeposited under the same conditions. The corrosion rate of Ni–SiC decreases by two orders of magnitude with respect to pure Ni coatings [Garcia et al., 2003]. In this work, SiC particles were incorporated into nickel phosphorus (Ni–P) alloy matrix by direct current plating and the effects of current density and SiC concentration on the compositions and the microhardness of the Ni–P–SiC deposits were investigated. The results reveal that increasing the current density or the SiC concentration in the bath increases the SiC content in the deposit. Adding SiC to the Ni–P alloy matrix substantially reduces the residual stress in the deposit and, therefore, eliminates surface cracking [Choua et al., 2005]. Electroless Ni–P coatings containing SiC particles were co-deposited on SKD61 tool steel substrate. The effect of heat treatment on the microstructure of Ni–P–SiC composite coatings was investigated by X-ray diffraction and transmission electron microscopy. The presence of SiC particles did not affect the microstructure of the Ni–P alloy matrix when annealing temperature was below 400 ºC. However, by increasing annealing temperature to 450ºC, SiC particles decomposed and reacted with nickel [Chen et al., 2002]. Several types of hard particles —SiC, Al_2O_3 and B —were co-deposited by electroless within a Ni–(8.22 wt%)P matrix, on 6063-T6 Al substrate.

Investigation of the Ni–P deposit structure by XRD and DSC revealed an amorphous phase with a crystallization temperature around 350°C. The heat treatment applied to achieve a maximum hardness of the coating caused a significant decrease of the 6063 Al microhardness due to coarsening of Mg_2Si precipitates and recrystallization of the Al matrix. Thus, for this substrate-coating system, heat treatments above 250°C are not recommended because the structural stability of the substrate, and consequently, its properties are negatively affected [Apachitei et al., 1998].

Pure nickel is non-toxic, can be deposited as an extremely bright, it has excellent resistance to corrosion and easily soldered. However, pure nickel is soft and is not practical to be used as coated material for automotive applications. Instead of plating of pure nickel nowadays, the metal is also combined with other elements in order to achieve alloy coatings and also composite coatings. Composite electroplating consists of a plating solution in which micron- or submicron-size particles are suspended. Metals, metal oxides, carbides, borides, and polymers were used as co- depositing particles. Variable amounts of these particles become embedded in the electrochemically produced solid phase and imparted special properties to deposited layers [Mordechay and Milan, 2000], [Ferkel, 1997] and [Benea et al., 2002]. Composite coatings produced by electroplating technique enhance physical and mechanical properties such as wear and corrosion resistance as compared to the pure metal coatings. These improved properties mainly derived from the presence of particles dispersed in the metallic matrix and depended on the content and nature of particles in the coatings. Among many methods of preparing such dispersion- hardened alloys, electro deposition is a simple and economic method of producing composite coatings [Loweinheim, 1978]. The referenced electrodeposited coatings exhibited better anti-wear performance than the electrolessly

deposited corresponding coatings [Nabeen et al., 2004]. Recently, in order to improve the physical and mechanical properties of coatings, many kinds of composite coatings based on nickel were developed by electro deposition method such Ni/SiC [Lee et al., 2007], Ni/ZrO_2 [Hou et al. , 2006], Ni/Al_2O_3 [Dong et al., 2006], Ni/WC [Surender et al., 2004] and Ni/B [Krishnaveni et al., 2006]. The use of Ni metal and alloy can give exceptional advantage in term of mechanical properties and physical properties. SiC particle has many superior properties, such as low price, good chemical stability, high microhardness and wears resistance at high temperature [Mangonon, 1998] & [Feng, 2007]. Therefore, as a second phase to strength composite materials, SiC is one of the candidate material. It should take into account the various properties, depending on both the electro and electroless plating techniques and hard particles addition. Wear and fatigue in contacting components are potential damage modes in assemblies to be resisted and minimized by design. As mentioned previously, the metal matrix composites containing ceramic particles as a distributed phase are useful in a lot of applications especially in the field of engineering as anti-wear andanti-frictional materials [Straffelini et al., 1999]. Furthermore, the mechanical and tribological properties of Ni coating can be improved by the incorporation of different solid particles which are categorized as hard and lubricating [Grosjean et al., 2001]. However, the coating hardness decreases correspondingly with the volume fraction of lubricating particles in the coating, and the friction coefficient becomes worse because of the hard particles. To solve the above problem, complex composite coatings containing both hard and lubricating particles are receiving increased interest. In order to improve the physical and mechanical properties of coatings, many kinds of composite coatings based on nickel were developed by electro and electroless deposition methods. In coating, the aggregate particles are held or linked together by a hardened composite coating. Therefore, the coating and particle properties are interconnected to each other. To determine the features of coating properties, it is necessary to know the features of the hard particle addition. Therefore, in order to get more understanding on the effects of different particles in coating, investigation on the characteristics of the hard particles addition are necessary. It is known that graphite (Cg) is a frequently used solid lubricant material and SiC particle has many superior properties, such as good chemical stability high microhardness and wear resistance at high-temperatures.

2.3 Coating for piston rings

The possibility of electro-codeposition of pure Ni, Ni-SiC, and Ni-Cg (graphite)-SiC composite coatings via electroplating in different electroplating bath solutions and its application onto actual piston rings of a small two stroke utility engine has been studied. By many factors that influence the composition and properties of coatings which are deposited from these different plating solutions are observed. The results are used to select the best operating conditions and composition of plating bath for syntheses of Ni-P-Cg (graphite)-SiC composite coating and its application onto piston rings of a small two stroke utility engine [Zeng and Zhang, 2007].

To meet more demanding fuel economy and emission standards, new challenges in engine design included reduced friction and wear. Reducing the fuel consumption and emissions of small two-stroke utility engines through experimental investigations of different surface coatings are increasing important due to high petroleum prices and concern for the environment. Piston-ring pack rubbing is responsible for the majority of the frictional losses in these engines. Approximately
53% of the friction losses are due to the piston-cylinder system [Ripin et al., 2007], of which 70–80% comes from the piston rings [Ryk and Etsion, 2006]. Mechanical friction can be reduced by improving design of rubbing and sliding surfaces or by using the right material coating to minimize the wear and friction. In the present study, it is focused more directly on the coating of piston rings by Ni-P-Cg (graphite)-SiC via electro and electrolessplating. Hardness, friction coefficient, roughness and the relative thickness of coating characteristics of Ni-P-Cg (graphite)- SiC composite coating on the actual piston rings was examined, and then compared with the actual standard piston rings in small 2-stroke utility engine, in order to increase the hardness of actual standard piston rings and reduce friction coefficient, roughness, fuel consumption, emission, and improve the efficiency of these engines.

2.4 Four principal parameters for coatings

Four principal parameters for coatings are hardness, coefficient of friction, roughness, and the thickness of coating.

2.4.1 Hardness of coatings

Hou et al., (2006) have evaluated the effect of the dispensability of ZrO_2 nanoparticles in Ni–ZrO_2 electroplated nanocomposite coatings on the mechanical properties of nanocomposite coatings. They have reported that ZrO_2 nanoparticles was uniformly co-deposited into a nickel matrix by electroplating of nickel from a Watts bath containing particles in suspension which were monodispersed with dispersant under DC electrodeposition condition. It was found that morphology, orientation and hardness of the nanocomposite coatings with monodispersed ZrO_2 nanoparticles had lots of difference from the nanocomposite coatings with agglomerated ZrO_2 nanoparticles and pure nickel coatings. In particular the result of hardness showed that the percent of monodispered ZrO_2 nanoparticles in Ni– ZrO_2 nanocomposite coatings resulted in higher hardness of the coatings. The hardness of Ni–ZrO_2 nanocomposite coatings with monodispersed and agglomerated ZrO_2 nanoparticles were 529 and 393 HV, respectively. All these composite coatings were two–three times higher than that of pure nickel plating (207 HV) prepared under the same condition. The strengthening mechanisms of the Ni–ZrO_2 nanocomposite coatings are based on a combination of grain refinement strengthening from nickel matrix grain refining and dispersion strengthening from dispersion state of ZrO_2 nanoparticles in the coatings. In order to compare differences, the plating bath was stirred by a magnetic stirrer. A copper plate with dimensions of 10 mm ×10 mm ×

0.25 mm was used as the cathode (sample of coating). The SEM micrograph from above study is given in Figure 2.1.

Figure 2.1 shows the morphology of particles in the composite coatings obtained from plating bath with and without dispersant PEDA (yellow-brown powder- kind of sulphonate). Figure 2.1A shows that ZrO_2 particles are fairly uniformly distributed throughout the Ni matrix when PEDA is added. However, many agglomerates of ZrO_2 particles are observed at the coatings prepared in the plating bath without PEDA (Figure 2.1B), and the ZrO_2 agglomerates are not uniformly distributed throughout the Ni matrix.

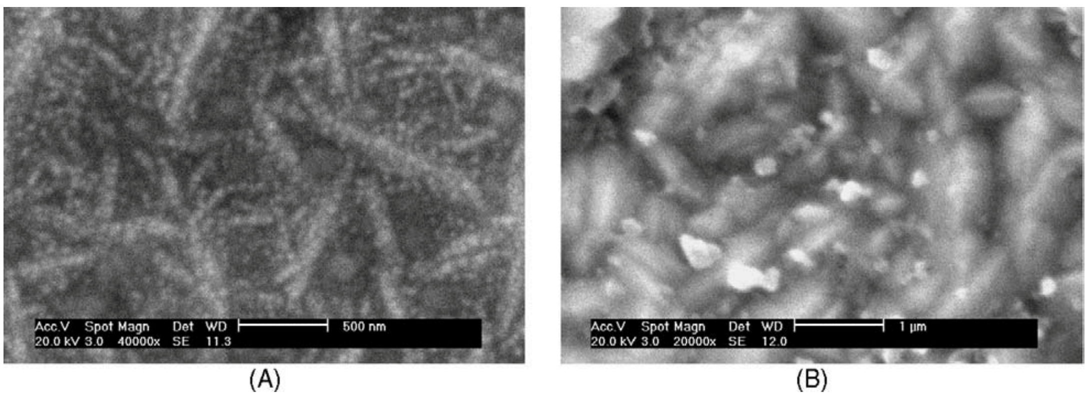

Figure 2.1: SEM micrograph of Ni–ZrO_2 composite coatings: (A) monodispersed ZrO_2 nanoparticles; and (B) agglomerated ZrO_2 nanoparticles [Hou et al., 2006]

Badarulzaman et al., (2008) have stated that a series of electroplating work conducted to investigate the best condition for the co-electrodeposition of nickel- alumina (Ni/Al_2O_3) composite coating. Coelectrodeposition was done onto mild steel as cathode (sample of coating). The highest hardness value of the coating was 401.8 Hv. Surface morphology of the composite coating from the study is shown in Figure 2.2. FESEM was applied for the surface morphology (Figure 2.2). In Figure 2.2(a), a typical surface morphology of Ni deposit was obtained. At the same time, Al_2O_3 particles could also be clearly observed at the coatings' surface, in Figure 2.2(b), the Ni matrix (light phase) and Al_2O_3 particles (dark phase) can be easily differentiate. In Figure

2.2(c), the micrograph indicates that the Al_2O_3 particles appeared to be perfectly embedded into the Ni matrix.

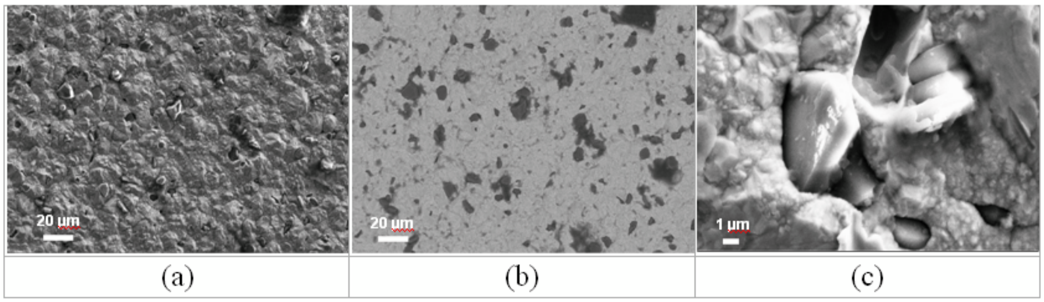

Figure 2.2: Surface morphology of the composite coating. (a) 500X, secondary electron mode, (b) 500X, back-scattered mode, and (c) 5000X, secondary electron mode [Badarulzaman et al., 2008].

They stated that the agitation rate of 250 rpm could be used for produces the best codeposition. Figure 2.3 shows the preliminary study on the cross sectional area of the composite coatings by means of a light optical microscopy at 200X magnification. The black spots at the Ni/Al_2O_3 layer represent the Al_2O_3 particles, the micrographs portrayed that by increasing the rate of agitation, definitely more Al_2O_3 particle can be co-deposited together with the Ni matrix. At 250 rpm agitation rate, it is very obvious that the co-deposition process yields the best composite coatings where more black spots can be seen embedded inside the Ni matrix.

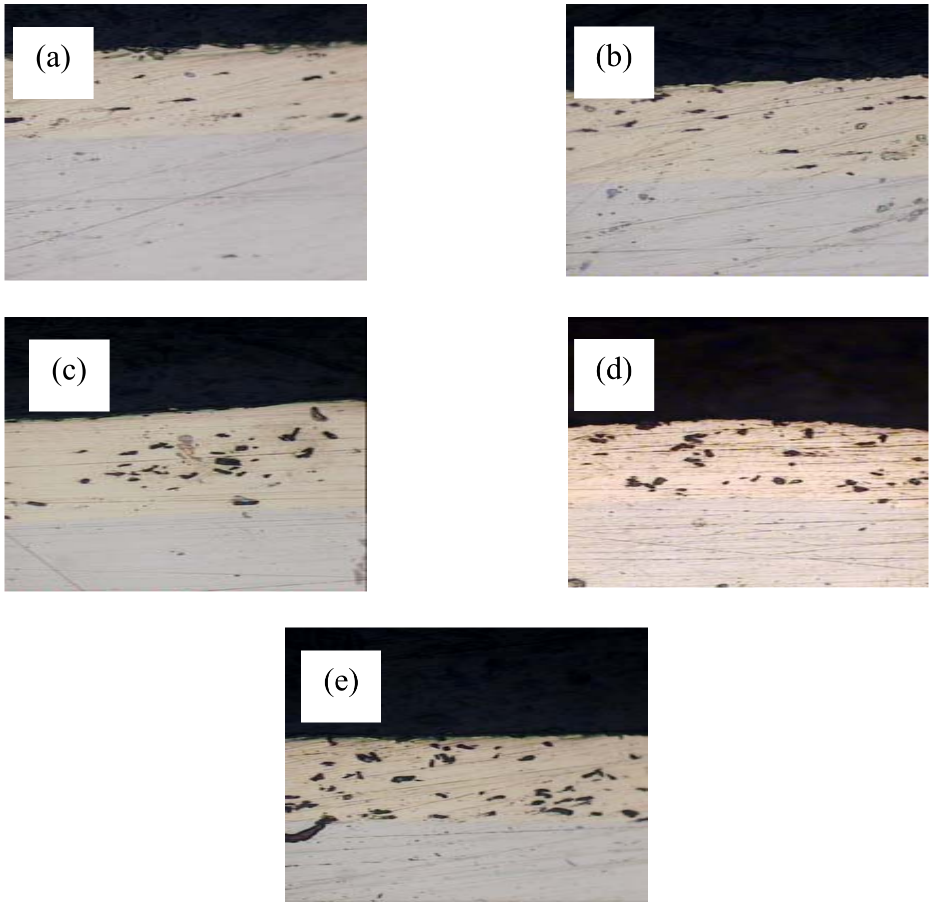

Figure 2.3: Light optical microscopy observation at 200X on the cross sectional view of the composite coating for co-deposition at agitation rate of (a) 50 rpm, (b) 100 rpm, (c) 150 rpm, (d) 200 rpm, and (e) 250 rpm [Badarulzaman et al., 2008].

Shafiei-Zarghani et al., (2009) have stated that the microhardness of the Al/Al_2O_3 surface nano-composites increases significantly with increasing number of friction stir processing (FSP) passes. The maximum microhardness for the surface composites was 295Hv, while that of the samples treated by the FSP without Al_2O_3 particles and the as-received Al were 67 and 110Hv, respectively. The SEM micrograph from the above study is shown in Figure 2.3. In the case of chemical deposits, different values have been reported. The hardness variations could be explained according to size and structure of powder, quantity of particles included in the deposits, load of indentation and the thickness of the coatings tested.

Figure 2.4 shows the SEM images obtained from the surface nanocomposites. The dark regions in Figure 2.4(a) are agglomerated Al_2O_3 particles, and the white particles are strengthening precipitates of 6082 Al which are dispersed in the Al matrix. The dispersion of the Al_2O_3 particles in the 6082 Al matrix was related to the number of passes. Agglomerated Al_2O_3 particles could be observed in the surface composite layer produced by one pass. The observed clustering particle size is frequently 100–200 nm, much larger than the individual Al_2O_3 size (50 nm). The situation after two to four passes appears to have further reduced the clustering Al_2O_3 size, as shown in Figures 2.4(b-c) for the surface composite layers produced by three and four passes. In comparison to the surface composite layer produced by one pass, the surface composite layer produced by three passes showed a better dispersion of Al_2O_3 particles. There were just a few regions which included the aggregated nano-sized Al_2O_3 particles. On the other hand, a good dispersion of nano-sized Al_2O_3 particles, which were separated from each other, could be observed for the surface composite layer produced by four passes.

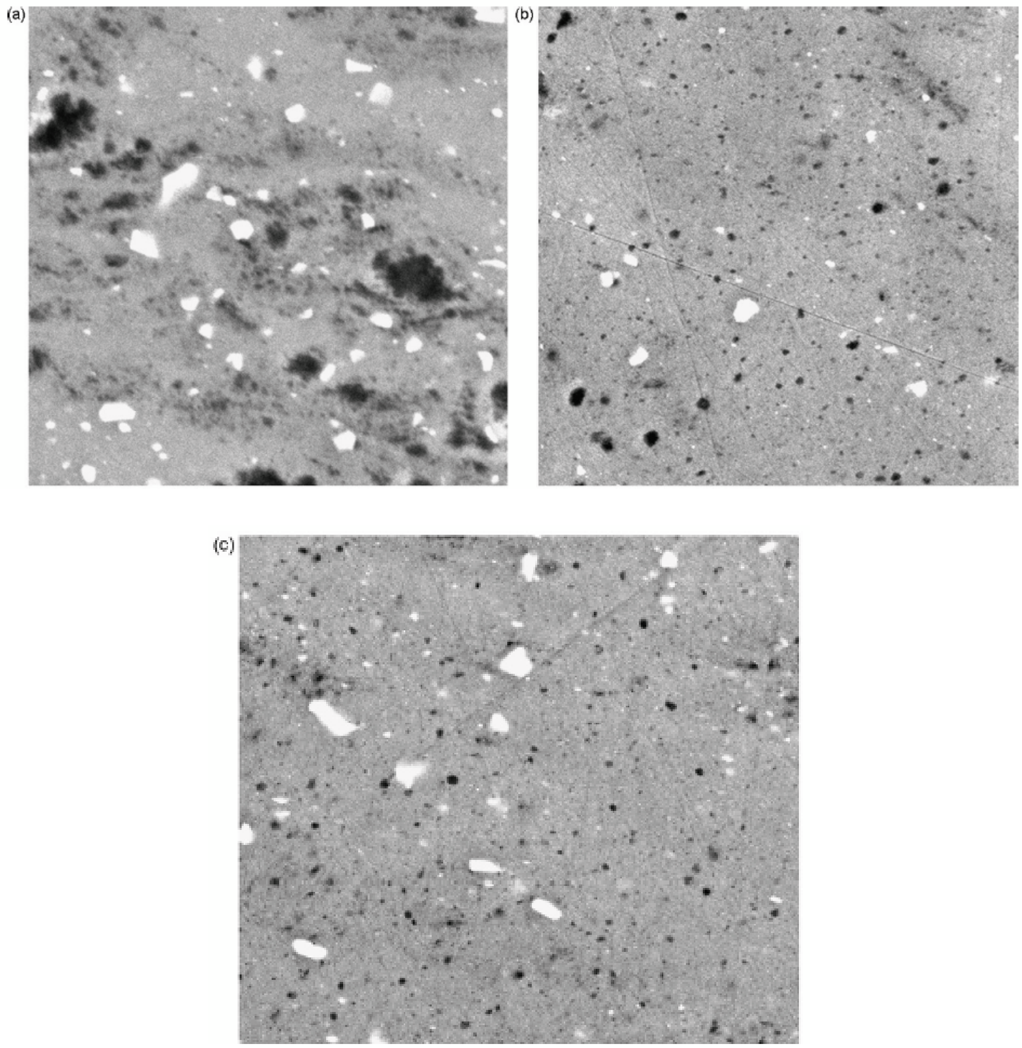

Figure 2.4: SEM images of the Al/Al_2O_3 surface composite layers produced by (a) one, (b) three, and (c) four FSP passes [Shafiei-Zarghani et al., 2009].

Huang et al., (2003) have studied electroless nickel (EN) composite coatings with polytetrafluoroethylene (PTFE) and SiC deposited using chemical depositionan technique. The microstructure analysis was conducted with scanning electron microscopy and X-ray diffraction. The mechanical and tribological properties were measured using hardness indentation. Where the highest hardness value for NiP– PTFE–SiC composite coating was 450 Hv. The SEM image from this study is shown in Figure 2.5.

Figure 2.5 shows the SEM micrographs of electroless nickel (EN) and EN composite coatings. All the samples studied had a thickness of approximately 15 μm. EN–PTFE and EN–SiC were deposited with PTFE or SiC particles uniformly distributed in coatings. However, when SiC and PTFE particles were deposited together, some interference effects occurred, resulting in the particles being nonuniformly distributed in the coatings. The SiC particles were much heavier than PTFE, which required strong agitation to keep them from flocculation. This affected the co-deposition and distribution of the PTFE particles in the coating.

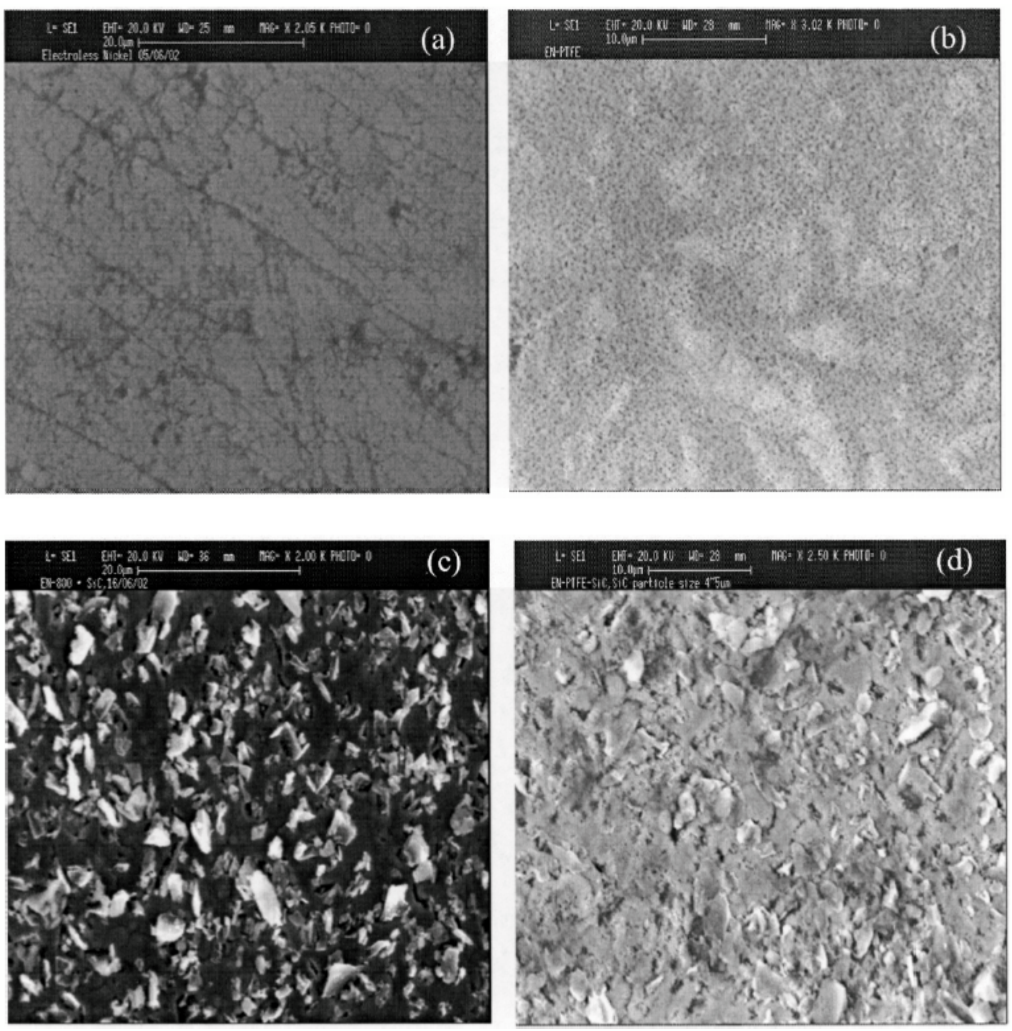

Figure 2.5: SEM images of (a) EN, (b) EN–PTFE, (c) EN–SiC and (d) EN–PTFE– SiC composite coatings [Huang et al., 2003].