Heat Transfer Behaviourof Electro Deposited Nickel-Tungsten Alloy Coating

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Abstract: Metal and alloys/ ceramic coatings have been widely employed for several decades for protection of components at high temperatures in power plant, gas turbines and oil refineries with great success. The high quality thermal barrier coatings are normally employed for this purpose in the elevated temperature services to protect the base materials from the severe operating thermo cyclic load conditions and to improve their performance. This paper deals with the convective heat transfer performance of nickel- tungsten particles deposited over the mild steel by selecting optimum conditions for the electro deposition technique for a thickness of 10 µm and 50 µm thickness.The characterizations of the coated surfaces were conducted by surface topography (XRD and SEM). The convective heat transfer studies of the nano-sized nickel tungsten alloy coatings reveal that a particle size of around 92 nm, exhibits nearly 10 to 14% of temperature reduction in 50 µm thickness coating, whereas the temperature reduction of 8 to 11% of was observed in 10 µm thickness coating.

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1. Introduction

Metals have a vital role from household to industrial applications that includes chemical industry, electronic equipment and industry, construction and medical field. Large unique and universal usefulness of steel, steel alloy and its derivatives always have an emerge demand. Stainless steel and mild steel are widely used in many chemical industries, because of their high corrosion resistance in aqueous environments. From the failure analysis, we know that extremely high working temperature, structural loading, latent defects, wear and corrosion are some general causes of failure of metals during the uses. Attempts have been made by researchers to improve the wear resistance of steel materials by coating process**.**Nowadays stainless steel is mainly used in various domestic appliances and many engineering applications. Due to its corrosive behaviour and cost effectiveness, it is essential to safe guard it from the working atmosphere.Proper coating is to be given to improve its life and efficient working (Kiruthika et al., 2010). The protective coatings over steel should have good oxidation resistance and wear properties. The coatings should have good thermal resistance to heat flow and should act as thermal barrier coatings. These thermal barrier coatings are widely used to protect many components used in high or elevated temperatures like aero space and gas turbine applications. Effective high-temperature barriers have an enormous need to extend the lifetime of the base metal. Longer component lifetime at constant service temperatures can be achieved by reduced corrosion and oxidation resistance (Setare et al., 2009). Thermal barrier coatings are used to develop an advanced gas turbine system for economical and environmental reasons (Kh.G schmitt, 2009& Yuri et al.,1997). Materials of high performance and reliability include high heat-resistant alloys and thermal barrier ceramic coatings. The materials used as coatings need to ensure effective protection against corrosion and erosion. They have a suitable thermal conductivity in order to provide good service behaviour as well as effective and economical maintenance layout (Lidia Benea et al., 2011).

The metal matrix and alloy coating can be produced through a number of routes including metal processing, plasma spraying, electro deposition, etc. Electro deposition is a room temperature process to deposit composite coatings in a single step. Composite electroplating is a method of co-depositing insoluble, dispersed particles of metallic or non-metallic compounds with metals or alloy in a plating bath, to improve the coating properties such as corrosion resistance, lubrication, hardness and wear resistance (Higuera Hidalgo et al ., 2001)

Tungsten and its alloys are in high favour due to their specific tribological, magnetic, electrical and electro-erosion properties.They may compete even with ceramics and graphite by virtue of their high thermal resistance (Atanssov et al., 1997). Tungsten cannot be electrodeposited directly from aqueous electrolytes, but can be co-deposited with iron group elements such as nickel to form an alloy (Brenner, 1963). The addition of tungsten into nickel enhances its properties like hardness and high temperature stability. Nickel-tungsten alloys are used due to their improved mechanical property and stability.They are used in cutting tools and other precision applications. (Liyanagea et al.,2012). Compared to other conventional methods, electroforms and alloys enhance the mechanical properties such as wear resistance, hardness and oxidation resistance. Electrodeposited nano-crystalline Nickel–Tungsten alloys are being considered as an attractive alternative to electrodeposited nickel. A number of studies have appeared on electrodeposited nickel–tungsten based alloys.

A comparative study of Nickel and Nickel tungsten alloys, and reported that the Nickel tungsten alloy electro-deposition exhibits better wear resistance than the Nickel electro-deposition. The tungsten in the Nickel tungsten alloy reduces the wear damage of the metal substrate (Haseeb et al., 2008).It was reported that the concentration of W in the plated alloy, has a major effect on the mechanical and chemical properties, such as hardness, abrasion resistance, and improved corrosion resistance at high temperatures. X-ray diffraction studies were conducted, and they indicated homogeneity, ascribable to a solid solution of W in Ni, This isinspite of the fact that some layered structures were observed in the deposit microstructure (Younes and Gileadi 2000).

This study demonstrates the convective heat transferbehavior of electro deposited nano crystalline nickel-tungsten alloy coating over mild steel substrate using a Ni sulphamate bath. The required thickness of the coatings is obtained by varying the deposition time, current density and composition of both. The convective heat transfer behaviour is studied for two different thicknesses of 10 µm and 50 µmthickness coating.

This paper is organized as follows. Section 2 gives a detailed description of the experimental work carried out to analyze the thermal characteristics of the nickel tungsten alloy coating. Section 3 describes the results obtained through various experiments to characterize the convective heat transfer behaviour of the coating. Finally, the important conclusions drawn from the proposed work are given in section 4.

2. Experimental Studies

An electroplating technique has been employed to produce nickel tungsten alloy coating over mild steel. Among the various baths, like sulphamate, watts, sulphate and bright nickel baths, the sulphamate bath is preferable because of its less internal stress behaviour (Kamel et al.,2010 &Imri Bakonyi et al.,1996). The literature cites the influence of various plating variables on the electro-deposition of Ni-W alloys, such as the concentration of metals in the electrolyte, pH, temperature, current density, stress reducers and complexing agents. A pure nickel plate (99.9% nickel) was used as an anode and a mild steel plate of dimensions 100 mm x100 mm x 5 mm acted as a cathode after the standard pre-treatment processes like solvent cleaning, alkaline cleaning and acid etching with intermittent de-ionized water washing. Based on Faraday’s law, the deposition time was adjusted to achieve an average coating thickness of 10 µm and 50 µm on the mild steel plate. Figure 1 shows the schematic diagramof deposited nano particle Nickel tungstencoating over mild steel substrate. The operating conditions for the nickel- tungsten alloy coating were fixed among the several set of conditions by the trial and error method, based on the literatures (Kar et al. & Islak et al.,2008).

Figure1. Schematic diagram of Nickel-Tungsten electro-deposit over mild steel sub strate

The structure of the coating was characterized by the Scanning Electron Microscope, and the particle size of the nickel tungsten coating was calculated by the X-ray diffraction (XRD) technique using the Scherrer’s formula (Perusin et al., 2004).

Figure 2 shows the schematic line drawing of the specially designed experimental set up and its essential features to measure heat transfer behaviour of coatings.In the experimental study, convective behaviour of the electrodeposited nano-crystalline nickel–tungsten coating on the mild steel specimen was studied with and without coating. The experimental set up for convection studies has a provision to expose hot air at different velocities and with various temperatures on the test specimen to study the convective heat transfer performance of the coated samples. An air blower which is the main source of hot air is used to supply the air through the 50mm diameter pipe section. A non return valve is located in the passage to regulate the flow of air through the conduit pipe. This surface of the pipe through which the air is flowing, is neatly covered by a heater wrapped over it and heat the air depends upon the energy supplied to the heater. An orifice plate of 15 mm diameter is fitted at the inlet of the pipe section to measure the velocity of air flowing through this pipe.

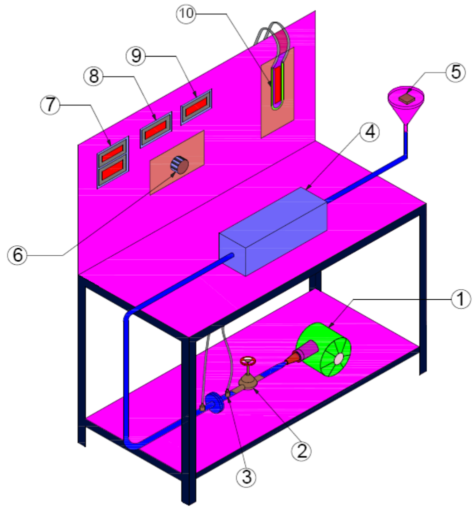

Figure 2. Schematic diagram of the experimental set up to study the convective heat transfer behaviour of the coatings [Not to scale] 1. Blower 2.Foot Valve. 3.Orifice meter. 4.Heating Section 5. Specimen. 6. Variac, 7.Temperature indicator. 8.Voltmeter. 9.Ammeter. 10.Manometer

A U-tube water manometer is attached to measure the discharge of the flowing air mounted on the panel board which is also having an ammeter, voltmeter , variac , digital temperature indicator and temperature selector switch . The outlet of the pipe section is formed like a funnel type portion in order to expose the hot air over the specimen. Two magnetic rods are employed to hold the specimen in the desired position and expose to the hot air stream. The convective performance tests are conducted for different velocities of air and with different energy inputs.

A high voltage DC power supply is utilized for supplying power for the experimental works carried out in the present study. The power supply can deliver a wide range of power to the heater according to our heat flux requirements. The instrument has regulated DC power output. Stainless steel sheathed thermocouples of K type are used for recording the temperature at several locations of the coated and un coated plates. The thermocouples are positioned in such a way that it always in contact with the surface to read the temperatures of the coating and steel plate. The thermocouples together with the compensating wires are connected to a data logger to record the temperature of the coated and un coated surfaces for various energy input All thermocouples have been calibrated before using them in the measurements. Thesestandard dimensions ofU tube manometer uses water as a manometric fluid which measures the flow through the pipe by measuring the differential pressure across the orifice through which the air is supplied to the system.

3. Results and Discussions

3.1 Surface Morphology

i) X-Ray Diffraction: The nickel-tungsten coating of 50 µm thickness was spread onthe mild steel plate. The surface morphology was analyzed by the X- ray diffraction unit, and the XRD pattern obtained is shown in Figure 3. The size of the particles deposited is confirmed by the XRD pattern. The peak of nickel-tungsten shows a texture pattern of [111]. Andthe mean particle size of the nickel tungsten coating is determined by using the Scherrer's formula and it is in the order of 92 nm.

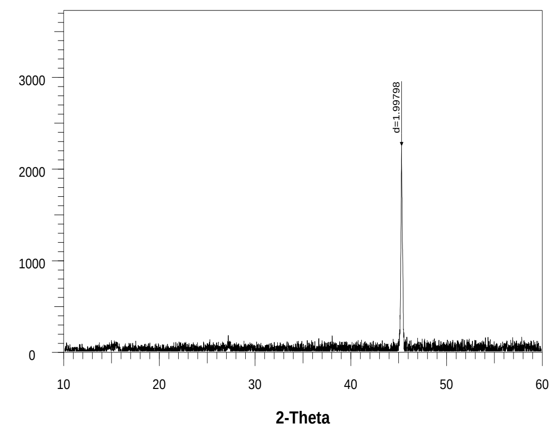

Figure 3. XRD pattern of Nickel tungsten (50 µm) coating

ii) Scanning Electron Microscope – SEM: The properties of electrodeposited coatings are determined mainly by their structure. Even minor structural differences have profound effects on the

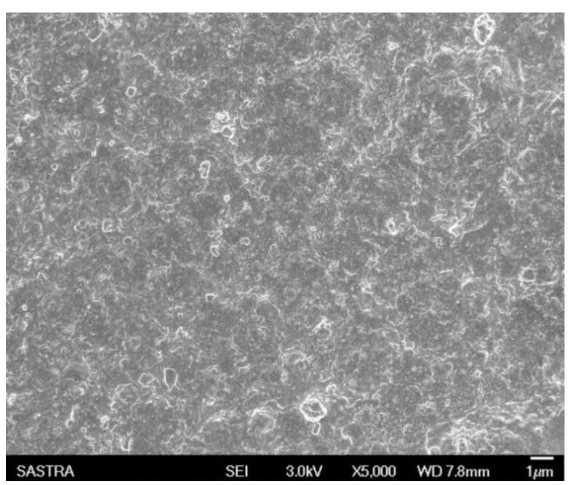

Figure 4. SEM image of nickel-tungsten (50 µm) coating

properties of deposits and incorporation of foreign materials modifies the structure of deposits. The

SEM images were taken after carefully cleaning the surface by a suitable abrasion cloth. The images of the nickel tungsten coating captured is shown in Figure 4 indicates that the uniform dispersement of tungsten particle in the nickel matrix. The uniform deposition and nano size of particles were responsible for the improved thermal resistance which is the desired property for thermal barrier coatings.

iii) Thermal studies: The mild steels specimen with and without the nickel- tungsten coating are placed over the passage of the hot air stream and the temperature of the other side surfaces are recorded. The velocity of the flowing air is varied with a help of non return valve and the temperature of the flowing air is varied by giving different energy input to the heater. The energy input of the system is varied to reach a maximum temperature of 270 ^{0}C. The tests are conducted in both 10 µm and 50 µm thickness coated surfaces. The experiments were conducted in different discharges of air flow and two set of readings [1. Full opening of the valve: Discharge = 6.994 $\times 10^{-3}$ m^3/s; Velocity =4.2 m/s and 2. 75 % of full opening: Discharge = 6.539 $\times 10^{-3}$ m^3/s; Velocity = 3.9 m/s] were discussed

Figures 5 and 6 explain the variation of temperature obtained for various energy input and different Reynolds number for the full opening condition of the valve [Full opening: Discharge = 6.994 $\times 10^{-3}$ m^3/s; Velocity =4.2 m/s]. The decrease in coated surface temperature was obtained for increase in Reynolds number as the kinematic viscosity of the air increases with increase in temperature. Figures 7 and 8 show the percentage reduction obtained in the 10 µm and 50 µm thickness coated surfaces for the same conditions as mentioned in the full opening conditions. In this full valve opening condition, nearly 8.5 to 11% of temperature reduction is observed in the coating thickness of 10 µm, whereas 11 to 13% temperature reduction in the thickness of 50 µm thickness coatings.

Figures 9 and 10 indicated the variation of temperature obtained for various energy input and different Reynolds number for the three fourth of valve opening condition. [75 % of opening: Discharge = 6.539 $\times 10^{-3}$ m^3/s; Velocity = 3.9 m/s].
In this valve opening condition, nearly 9 to 11% of temperature reduction is obtained in the coating thickness of 10 µm, whereas 11 to 13.5 % temperature reduction in the thickness of 50 µm thickness coatings as indicated in the figures 11 and 12.

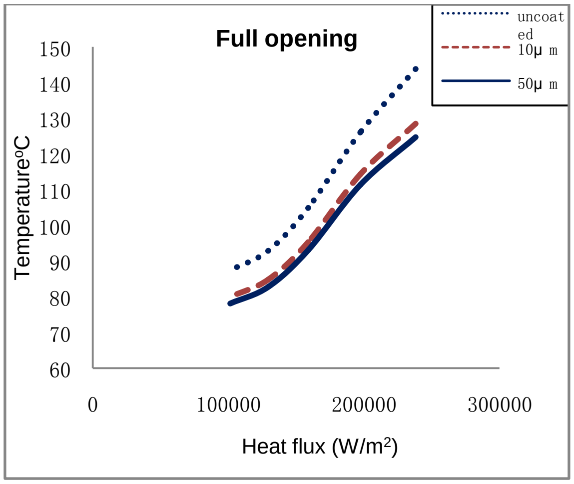

Figure 5. Temperature -Heat Flux History

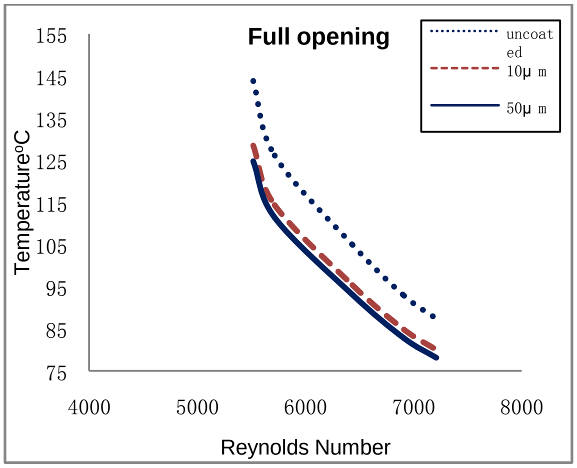

Figure6. Temperature VsReynolds number

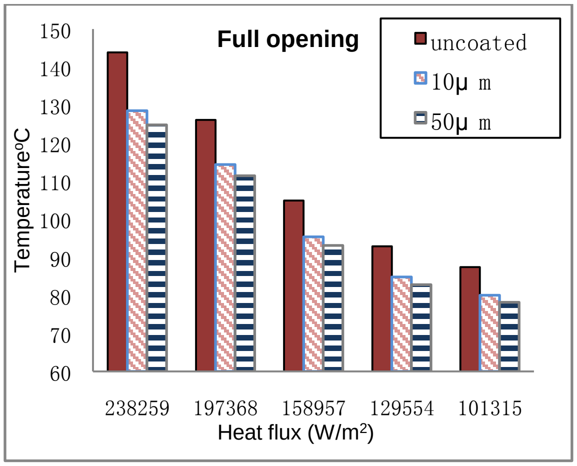

Figure7. Temperature -Heat Flux History

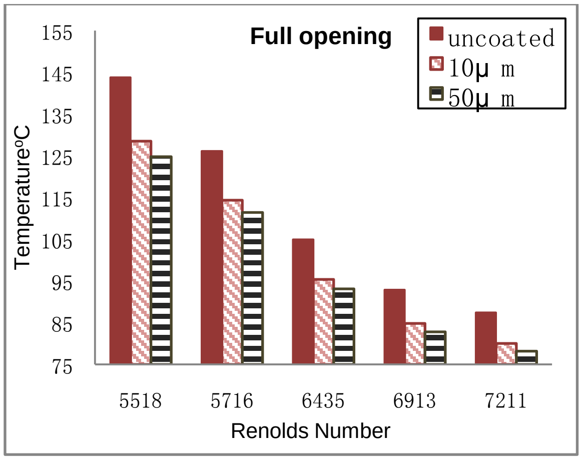

Figure 8Temperature VsReynolds number

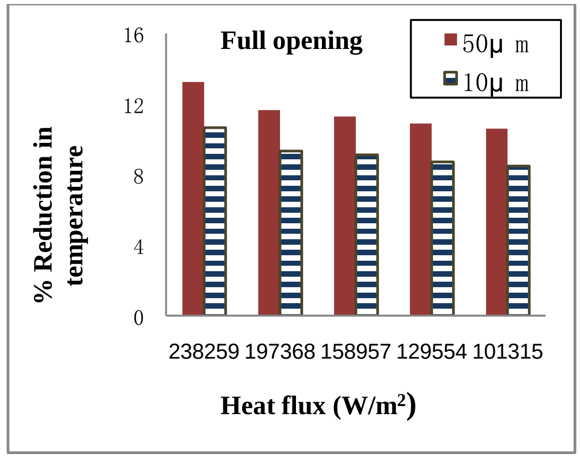

Figure11. Percentage reduction history

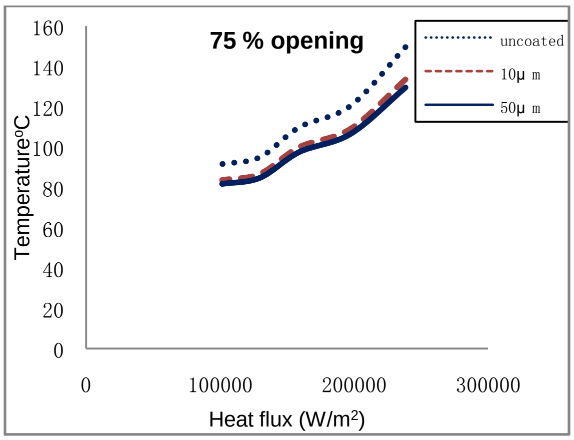

Figure 9. Temperature Heat Flux History

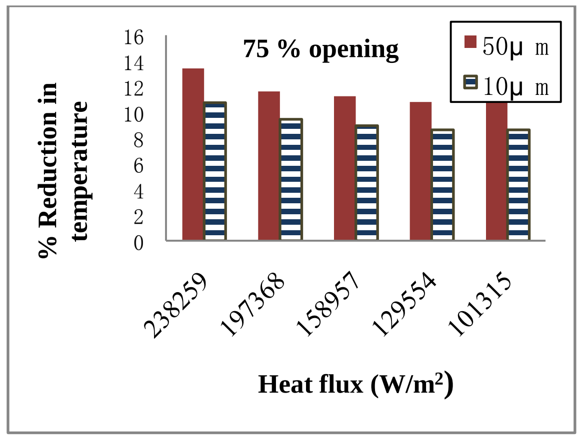

Figure12. Percentage reduction history

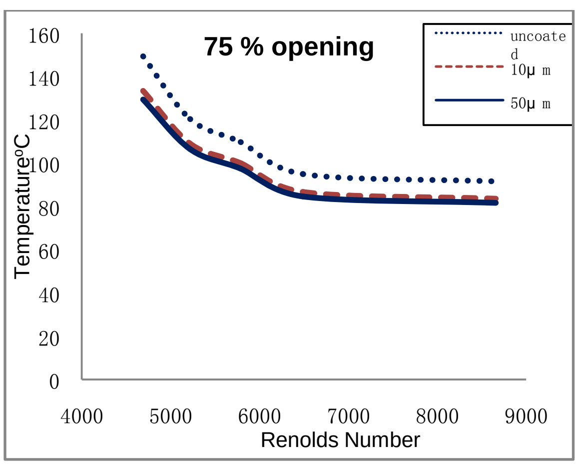

Figure 10.Temperature VsReynolds number

4. Conclusions.

This work demonstrated the convective heat transfer behaviour of the nickel-tungsten coatings which are produced by electro deposition technique of 10 µm and 50 µm thickness which is exposed to a hot air stream of maximum temperature of 270^{0}C. From the XRD studies, the particle size of the coating was observed as 90 nanometres and the same is also confirmed by the SEM images. Tungsten particles are located in the nickel boundary and due to this encapsulation of the nickel ions by nano-tungsten particles; 10 to 14% of temperature reduction was observed in the higher thickness coating (50 µm), whereas 8 to 11% of temperature reduction was noticed in lower thickness coatings (10 µm) deposited over the mild steel plate.

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References:

[1] Kiruthika.P, Subasri.R, Jyothirmayi A., SarvaniK, Hebalkar N Y , Effect of plasma surface treatment on mechanical and corrosion protection properties of UV-curable sol-gel based GPTS-ZrO2 coatings on mild steel, Surface & Coatings Technology, 2010;(204);1270–1276 .

[2] Setare.E, Raeissi.K ,Golozar M.A, Fath M.H , The structure and corrosion barrier performance of nanocrystalline zirconia electrodeposited coating, Corrosion Science, 2009;(51);1802–1808.

[3] Schmitt-ThomasKh.G, (1997),"Modifications of thermal barrier coatings (TBCs)", Surface and Coatings Technology , 94-95;149-154.(3)

[4] Yuri I, Hisamatsu T, Watanabe K, Etori.Y Trans. ASME J.Eng. Gas Turbines Power 1997;(119) 506–511.

[5] Lidia Benea, Pierre Ponthiaux, Francois Wenger , Co-ZrO_2 electrodeposited composite coatings exhibiting improved micro hardness and corrosion behavior in simulating body fluid solution, Surface & Coatings Technology, 2011;(205) ; 5379–5386.

[6] HigueraHidalgo.V,Belzunce F.J Varela, Carriles Menendez A , Poveda Martınez .S, comparative study of high-temperature erosion wear of plasmasprayedNiCrBSiFe and WC–NiCrBSiFe coatings under simulated coal-fired boiler conditions, Tribology International, 2001;(34) ;161–169.

[7] Atanassov.N,Gencheva.K, and Bratoeva.M, Plating and surface finishing,1997;84(2); 67

[8] Brenner.A, Electrodeposition of Alloys, Academic Press, New York, 1963;(2);345.

[9] Liyanagea.T,Fisherb.G, Gerlich, Microstructures A.P, and abrasive wear performance of PTAW deposited Ni–WC overlays using different Ni-alloy chemistries, Wear, 2012;(275);345– 354.

[10] Haseeb A.S.M.A., Albers U., Bade K., Friction and wear characteristics of electrodeposited nanocrystalline nickel–tungsten alloy films, Wear, 2008;(264);106–112.

[11] Younes O., Gileadi E., "Electroplating of high tungsten content Ni-W alloy", Electrochemical and solid state letters, 2000;(12); 543-545.

[12] Kamel M.M,Anwer Z.H, Abdel-SalemIIbrahim I.T, Nickel Electrodeposition from novel lactate bath, Institute of Metal Finishings, 2010;(88); 191-197.

[13] Imre Bakonyi, Enikő Tóth-Kádár, Lajos Pogány, Ágnes Cziráki, Imre Gerőcs, Katalin Varga-Josepovits, Birgit Arnold, Klaus Wetzig, Preparation and Characterization of D.C-plated Nanocrystalline Nickel Deposits, Surface and Coatings Technology, Issues 1-3, 1996;(78); 124-136.

[14] Kar, Soumen; Sarma, Sriram E; Somu, Kishore V B, Srinivas N K, Evaluation of different consolidation methods for nano-materials, Indian Journal of Engineering and Material Science, No. 4, 2008;(15) ; 343-346.

[15] Islak, Serkan; Buytoz, Soner; Karagöz, Muzaffer, Microstructural development on AISI 1060 steel by FeW/B_4C composite coating produced by using tungsten inert gas (TIG) process, Indian Journal of Engineering and Material Science, No. 4, 2008;(15); 343-346.

[16] Perusin S., Viguier.B, Salabura.J.C, QuabD.O, Andrieu E., Behaviour of the oxide scale during SEM in situ plastic deformation of pure nickel foil, Material Science and Engineering. 2004(387-389); 763–767.

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