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New Solar Selective Surface Coatings: A Review

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Abstract: An ideal solar selective surface coating must have good optical properties like high solar absorptance and minimum solar emittance. A new and affordable solar selective surface coating having higher solar absorption efficiency with low in-frared emittance compared to the commercial black paint coating used in most ordinary solar water heating systems has been developed. Such as solar selective coatings like black Nickel-Aluminium alloy particles with commercial black paint. Also, soalar selective surface coating with black nickel-cobalt plating on aluminium alloy substrates with nickel undercoat has been developed. Characterization study of such solar selective coatings is done in this paper. Characterization of coating includes Spectroscopic studies, Surface morphology and XRD studies, Polarization studies for corrosion resistance.

Keywords: Nickel-Cobalt coating, solar selective coating. Metallic Nickel-Aluminium alloy particles, solar absorptance, and solar emittance.

1. INTRODUCTION

The investigation and preparation of new solar selective paints for solar collectors has attracted much attention in many developing countries including the Middle East. There exists a few solar selective paints with good efficiency such as Solokte (solec, USA), Solarect-Z (Slovenia) and Thurmalox (Dampney.USA).Most of these paints have to be brought from their original modifiers and can not be used by the many people around the world due to their high import and tax costs[1].

Solar selective black chrome coatings are widely used for decorative as well as functional applications because of their durability and excellent optical properties. Though black chrome coatings provide excellent properties, the use of toxic hexavalent chromium and requirement of high current densities are the major drawbacks in producing these coatings [3].

Several alternatives to black chrome plating like black nickel, black nickel–cobalt, black brass, and black cobalt have been studied by several investigators [4-7]. Recently, metallic and non-metallic nanoparticles have been applied in solar-energy applications by the researchers like absorbing films consisting of nickel nanoparticles embedded in dielectric matrix of alumina Al_2O_3[8].Carbon nano-particles in NiO, ZnO, SiO matrices[9]. But these selective coatings have not been experimentally tested on solar heaters. The surface morphology of black nickel, black nickel-cobalt coatings and its relationship with optical properties have been studied on zincated substrates [10].

2. NEW SOLAR SELECTIVE SURFACE COATINGS

A) Modified coating which is based on black **Ni-Al particles** which is to be mixed with commercial black paint. Individually, nickel and aluminium have interesting thermal and spectral selective properties. Moreover, nickel exhibits good corrosion resistance and when added to coatings, it is known to improve their heat resistance and durability. Nickel exhibits high solar absorptivity. Aluminium has high reflectivity in the infrared region of the spectrum which guarantees low thermal emission caused by infrared radiant emission from the collector to the ambient. Therefore, it makes a lot of sense to try a new coating formula based on both metals.

2.1A) EXPRIMENTAL WORK

a) Required Materials

Black paint (cellulose nitrate resin, National Paints Inc., Jordan), acetone (Aldrich), nickel–aluminium alloy (50:50, BDH, UK), hydrochloric acid (BDH, UK), sodium chloride (99.9%, Aldrich) and two commercial solar water heaters.

b) The coating Process.

An electric mixer shown in fig 1.was used to mix the paint with the Ni-Al particles to produce homogeneous coating. A mixture of various percentages of NiAl alloy and the black paint were made by mixing and then diluted with acetone to ease the application of a uniform layer by immersion or brush painting on base metal like aluminium, copper, steel.

Fig.1: Electric Mixer

C) EXPERIMENTATION

In below Table 1. Shows different compositions for all coating tested.

Sample	Black-paint %	Ni-Al %	Acetone (ml)
1	100	0	50
2	97	3	50
3	94	6	50
4	91	9	50
5	82	18	50

Table 1: Different compositions for samples

An experiment was conducted on five 20-cm steel tubes filled with stationary water and fitted with a thermometer to compare the different compositions' absorbance to sunlight. The first tube was painted with commercial black paint and the other four were painted with the various compositions of the modified paint shown in Table 1 (samples 2–5). The temperature was monitored over a period of 1 week. The preliminary results showed that increasing the NiAl percentage increases the solar heat absorbance. There were no visual defects in samples 2, 3 and 4. Hence, the optimum composition to be further tested was chosen to be 6% NiAl by mass. For the performance study of the main solar water heating systems (SWHSs), the steel pipes of both systems were degreased with acetone and then etched with diluted hydrochloric acid (1.0 M) then washed well with water, followed by treatment with sand paper (fine grit) to provide good paint adherence. The bare steel tubes were then carefully painted giving a thin homogeneous layer and left to dry protected from dust in air for 48 h. A photograph of the experimental setup is shown in Fig. 2. It consists of two identical simple SWHSs where each is made of a flat plate collector and a storage tank.

Fig.2: A Photograph of Experimental Setup

All temperature measurements were performed using standard laboratory mercury-filled thermometers calibrated using a calibrated digital thermometer. The temperature measuring locations in the system are marked with the letter (T1 and T2) in Fig. 2. The probes were immersed inside the tubes and sealed with high quality silicon at the inlets and the outlets of the collectors. The temperature inside the storage tanks and the ambient air temperature were measured, as well. All temperatures were recorded every hour from sunshine to sunset (e.g. 9 am to 7 pm in the summer). The measurements were carried out regularly from May 2008 to April 2009 to cover both hot and cold seasons.

d) Laboratory Measurements

i) The transmittance and reflectance at normal incidence of the 6% NiAl-paint and blank paint samples were measured using a Shimadzu UV-3101PC.

ii) Surface morphological studies for the different coating samples were carried out with scanning electron microscope (SEM).

iii) The corrosion behaviour of steel coated with the modified and the unmodified paint was investigated by potentiodynamic polarization.

2.2. A) RESULTS

i) Spectroscopic Studies

As shown in fig.3, the higher the NiAl percentage the lower the transmittance values in the studied wavelength range.

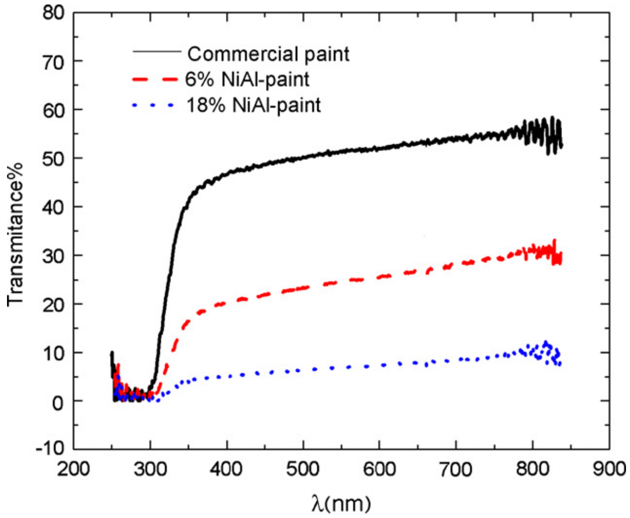

Fig.3. Transmittance of coated samples

Fig. 4 shows the absorbance characteristics of the modified and the unmodified paint samples. Despite of the limited wavelength range, the measurement clearly shows that the modified paint has greater absorbance efficiency over the unmodified paint.

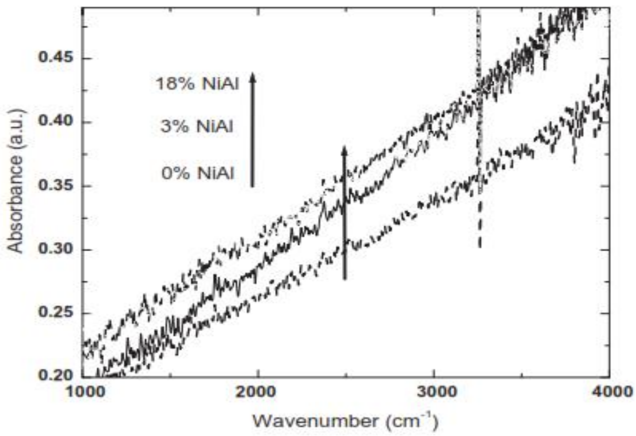

Fig.4. Absorbance spectral characteristics of the unmodified modified paint.

ii) Surface morphology and XRD studies

Below fig.5 represents micrographs of surface of the black paint shown in fig. (a) and the Ni-Al alloy modified coating on steel surface shown in fig. (b)

The uniform dispersion of the Ni-Al particles is a major factor in the enhancement of the solar absorptivity and the reduction of thermal losses.

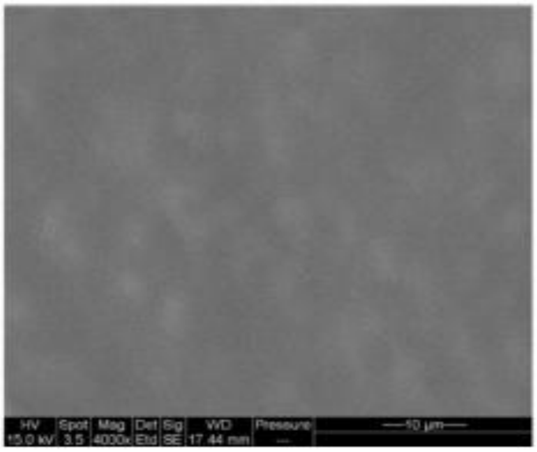

Fig.5.a) Micrographs of surface of the black paint.

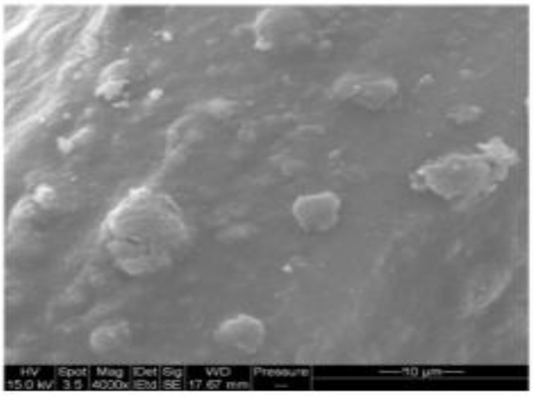

Fig.5.b) Micrographs Ni-Al modified coating on steel surface.

XRD study showed that the modified coating contains Ni and Al with no oxide detected.

iii) Corrosion studies

Below fig.6 shows that NiAl-modified paint is more effective as a corrosion inhibitor compared to the commercial paint and more importantly that the presence of metallic particles does not increase the corrosion rate.

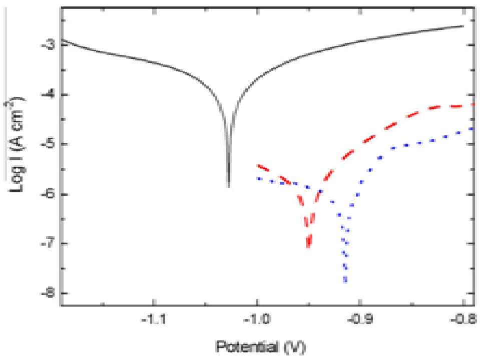

Fig.6.Polarization curves of untreated steel (solid), commercial paint coated steel (dashed) and NiAl-midified paint-coated steel (dotted).

iv) Solar collector temperature performance studies

From below fig.7 it is clear that the NiAl-modified paint always gave higher temperature for the water inside the collector.

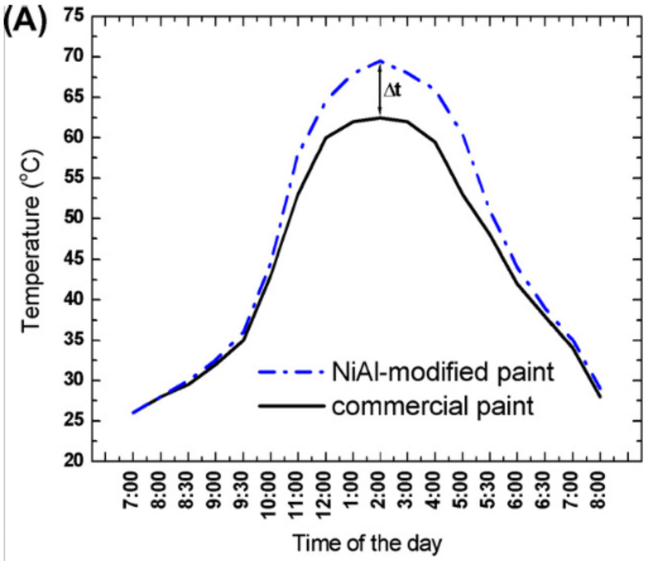

Fig.7 .Temperature curve for Ni-Al modified and commercial black paint of solar collector.

B) Solar selective black nickel–cobalt coatings on aluminium alloys.

2.1B) EXPRIMENTAL WORK

a) Required Materials

Aluminium alloy 6061 (Al-97.9, Mg-1.0, Si-0.6, Cu-0.25, Cr-0.25%) specimens of the size 100×50×2mm were processed for black nickel–cobalt plating.

b) The coating Process.

As per the following sequence of operations:

i) Solvent degreasing in trichloroethylene using an ultrasonic bath for 5–10 min at room temperature.

ii) Alkaline cleaning in a solution containing sodium carbonate 20–25 g/L, sodium meta silicate 8–12 g/L and tri sodium orthophosphate, at 65°C for 3–4 min followed by water rinsing.

iii) Chemical polishing[11] in a solution containing orthophosphoric acid 80%, nitric acid 3.5% and copper 0.01% for 20–25 s at 90 1C followed by hot water rinse.

iv) De-smutting in an acid solution containing 10 ml/L sulfuric acid, 12 ml/L hydrofluoric acid and 25 ml/L nitric acid for 2–3 min at room temperature followed by water rinsing and air drying.

v) Nickel plating using watts bath [12].

vi) Black nickel cobalt plating in a solution containing cobalt sulfate, nickel sulfate, ammonium acetate and sodium thiocyanate at 28–30°C, 40 A/ft^2 Measurement techniques for 30–45 second.

d) Laboratory Measurements

i) Surface morphological studies were carried out with scanning electron microscope (JEOL, JSM 840-A)

ii) X-ray diffraction (XRD) patterns of the coatings were obtained by Philips.PW 1140/90.

iii) Corrosion resistance of the black nickel cobalt coatings was evaluated by galvanostatic polarization experiments using potentiostat/galvanostat (362A, PG and PAR, USA).

iv) Optical properties (solar absorptance and infrared emittance) of all the specimens were measured by using a solar reflectometer version 50, model SSR-ER and missometer model RD1.

2.2. B) RESULTS

a) Effect of nickel undercoat thickness on optical properties of black Ni–Co coatings.

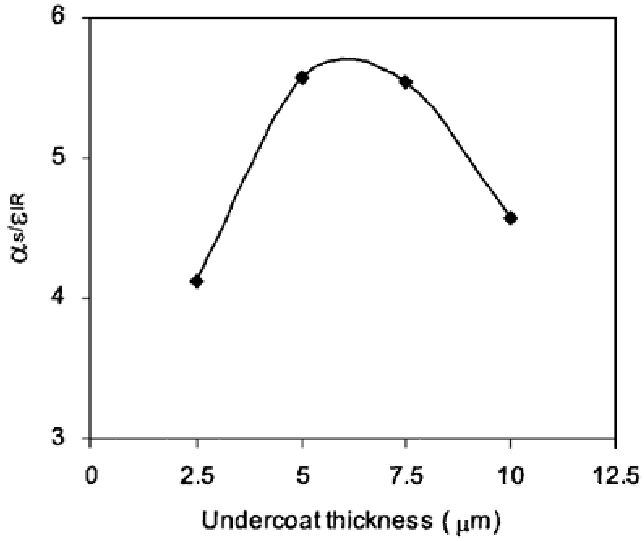

Fig.8. Effect of under coat thickness on the optical properties (ratio of absorptivity to the emissivity)

Fig.8. shows that depicts the influence of the thickness of nickel undercoat on the optical properties of the black nickel–cobalt coatings. The nickel undercoat thickness was varied from 2.5 to 10 µm. Lower nickel undercoat thickness resulted in a gray colored black nickel cobalt coating with low absorptance to emittance ratio. At 5.0–7.5 µm undercoat thickness a good black Ni–Co coating with high absorptance to emittance ratio (5.57) is obtained. Further there will decrease in absorptance to emittance ratio with increase in undercoat thickness.

ii) Surface morphology and XRD studies

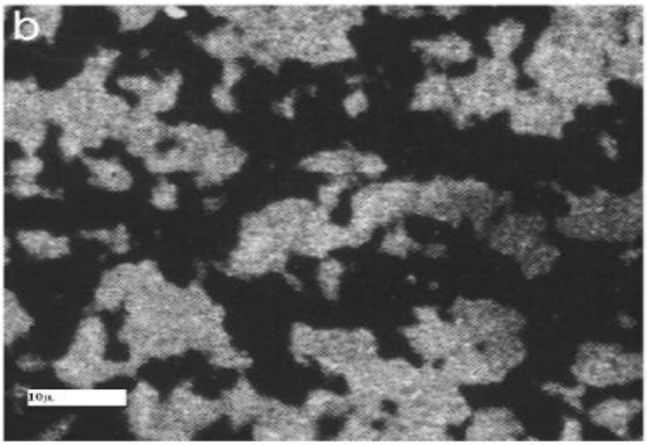

Fig.9.Micrographs of black nickel cobalt coating on nickel plated aluminium substrate.

Fig.9.depicts the surface morphology of black nickel–cobalt coatings on nickel-plated aluminum substrates. Surface morphology of the coatings affects the solar absorptance of the coatings. The enhancement of solar absorptance may occur either by an array of fine particles causing intrinsic adsorption or by reducing the

front surface reflections from an absorber surface. The particles have irregular needle like shape shown in fig.9, also the grains are compact, have more uniform structure in nickel-plated substrate. The irregular and needle like structure facilitates trapping of radiation so that the solar energy is absorbed by the black coating to a greater extent.

XRD pattern of the black nickel cobalt coating (25–50 nm) with nickel undercoat is given in fig.10.

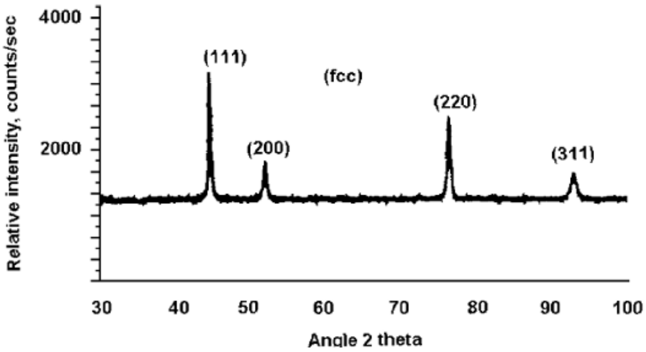

Fig.10. XRD pattern of black nickel cobalt coating.

XRD pattern shows the presence of fcc structure with major intensity Ni (1 1 1) peak and very small intensity Ni–Co peaks.

iii) Corrosion studies

Galvanostatic polarization experiments were carried out in a three compartment cell containing 5% NaCl solution at pH 5.0 using potentiostat/galvanostat (362 A, PG and PAR USA) to study the corrosion resistance of the coating shown in fig.11.

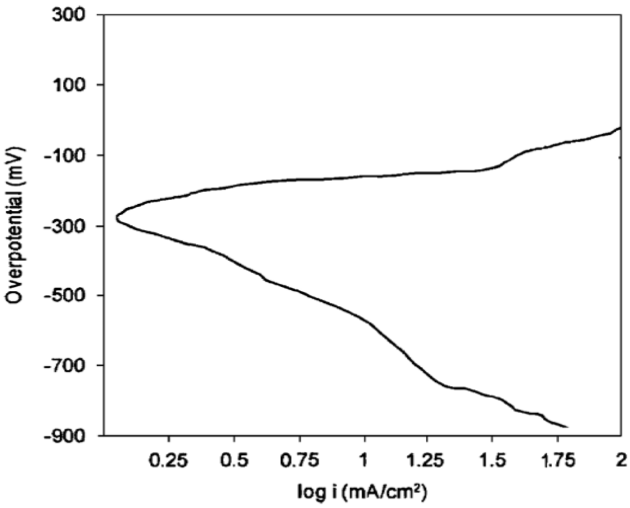

Fig.11. Polarization diagram of black Ni–Co coating.

iv) Measurement of optical properties

As the present studies are undertaken to develop solar selective coatings, the optical properties of the black nickel–cobalt coatings were carefully measured. The average value of solar absorptance and infrared emittance of the coating was measured for the best specimens. The reflectance spectrum of the black nickel–cobalt coatings obtained under optimum experimental conditions is presented in fig.12.

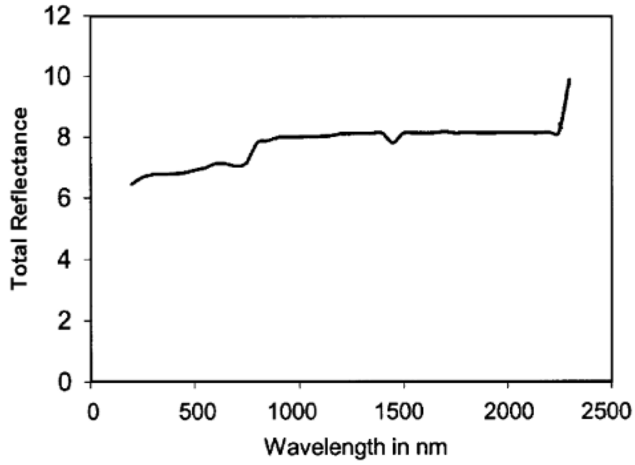

Fig.12. Solar reflectance spectra of black nickel–cobalt coating.

3. CONCLUSIONS

This review paper provides an overview of new solar selective coatings which are comparatively more efficient than commercial black paint used in various applications. The new coating, comprising NiAl alloy particles, shows that the solar water heater system collect thermal energy more efficiently than ordinary commercial black paint. From the outdoor experimental study, the new system always produced warmer water. The corrosion study proved that the metallic particles, in fact, increase the corrosion resistance of the paint. Also the black nickel cobalt electroplating on aluminium alloys process provides high solar absorptance (0.948) and low thermal emittance (0.17), which is suitable for solar selective applications. Scanning electron microscopic studies showed that the particles in the coatings are of dentritic structure. The high degree of solar absorptance is related to the irregular dentritic structure and surface roughness of the coatings. Polarization studies showed that the nickel cobalt coatings exhibit good corrosion resistance.

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