OPTIMISATION OF PLATING PARAMETERS AND PERFORMANCE ANALYSIS OF BLACK CHROMIUM COATING FOR SOLAR THERMAL ENERGY APPLICATIONS

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DEDICATIONS

To my beloved father, mother and wife, you are my inspiration

and

to all my friends for your help and support.

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ABSTRACT

Black chromium coating (BCC) is well known to give high performance in absorbing high solar radiation and low emittance in solar spectrum near infrared region. Different composition and plating parameters of the black chromium solution will give various combinations of the coating optical property and performance. The purpose of this study is to determine the optimum plating parameters using the coating solutions, which had been modified by the current work, in order to improve the optical properties and the performance of the coating. The coatings were produced from fluoride and borate baths. Newly improved fluoride baths have better throwing power and have the potential for shorter plating time from 2 to 6 minutes with excellent black coating compared to borate baths which have higher plating time from 4 to 10 minutes which is powdery and dull black in colour. It was also found that the absorptance (α) and emittance (ε) values of the coating that were determined by scanning infrared spectrophotometer technique were affected by the plating parameters. The plating parameters such as plating time, bath temperature and current density, affect the grain size and distribution of surface morphology which were observed under scanning electron microscope. Coating performance which is determined by using differential thermal analyser, humidity-thermal cycle cracking, sunshine weather-ometer and salt spray tests, shows that improved fluoride black chromium coating is better than borate black chromium coating. The coating gives good thermal stability at temperature around 1300 C, excellent humidity, resistance to weather and corrosion and good coating adhesion. It is found that the coating performance is dependent on the plating parameters for both newly improved baths that should be kept between its parameter limits in order to produce good chromium coating for solar thermal application.

ABSTRAK

Penyaduran kromium hitam (BCC) terkenal di dalam memberi kecekapan yang tinggi untuk menyerap tenaga suria serta mempunyai kadar pembalikan yang rendah dalam lingkungan spektra infra merah. Komposisi bahan larutan dan parameter saduran yang berlainan didapati memberi pelbagai keputusan dari segi prestasi penyerapan tenaga suria mahupun sifat saduran bahan. Oleh itu, penyelidikan ini bertujuan untuk mendapatkan parameter optimum dengan menggunakan bahan larutan baru yang telah diubahsuai oleh penyelidik bagi mempertingkatkan ciri optik dan prestasi saduran. Saduran kromium hitam ini dihasilkan dari larutan florida dan borat. Larutan florida yang telah diubahsuai mempunyai kuasa balingan dan upaya untuk masa lebih pendek iaitu daripada 2 hingga 6 minit dengan menghasilkan saduran hitam yang berkualiti jika dibandingkan dengan larutan borat yang mengambil masa penyaduran yang lebih lama iaitu daripada 4 hingga 10 minit serta menghasilkan saduran yang berserbuk dan bewarna hitam pudar. Kajian turut mendapati bahawa nilai penyerapan (α) dan pembalikan (ε) bahan saduran kromium hitam yang diuji menggunakan mesin spektrofotometer infra merah imbasan elektron dipengaruhi oleh parameter panyaduran. Faktor masa, suhu larutan dan ketumpatan arus juga turut mempengaruhi struktur permukaan bahan saduran, taburan dan saiz bijian yang mana ia dikaji dengan menggunakan mikroskop imbasa elektron. Prestasi saduran kromium hitam ditentukan dengan menggunakan alat penganalisa perbezaan terma, ujian kelembapan udara, ujian ketahanan cuaca dan ujian percikan air garam menunjukkan bahawa saduran kromium hitam dari larutan florida memberi keputusan prestasi keseluruhan yang lebih baik daripada saduran borat. Saduran ini memberikan kestabilan haba sehingga mencapai 1300^0C, kelembapan udara terbaik, ketahanan kepada kakisan dan cuaca, dan kelekatan yang baik. Hasil dari penyelidikan ini juga menunjukkan bahawa parameter saduran memberi kesan kepada prestasi saduran bagi kedua-dua larutan florida dan borat yang telah diubahsuai. Larutan ini perlu digunakan dalam had parameter untuk menghasilkan saduran kromium hitam yang baik untuk penggunaan penyerapan tenaga suria.

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F	Faraday constant. 96500C
I	Current in amperes
I_λ	Solar spectral irradiance
R_λ	Ideal selective surface
T	Temperature
t	time
W_λ	Blackbody spectral radiant
w	Weight of metal deposited
z	Valency of metal in the solution

Greek Symbols

α	Absorptance, solar altitude angle,
ε	Emittance
ρ	Reflectance
λ	Radiation Wavelength
ρ_λ	Monochromatic angular-hemispherical reflectance of a surface

CHAPTER I

INTRODUCTION

1.1 Prologue

The Harare announcement (Hussein, 1998) in October 1996, has open the eyes of the United Nation Educational, Scientific and Cultural Organisation (Unesco) to utilise the full use of the solar energy and further developing a solar energy programme. The programme highlighted the world usage of the solar energy for the community development and so far Unesco has successfully formed nearly 300 main solar energy project internationally. These programmes were supported by the Prime Minister of Malaysia himself. He had encouraged all researchers and academicians both in the government and private sector to move forward to develop the solar energy programme in Malaysia.

In accordance of the above announcement, this work is aimed at studying the effect of the thermal application of the black chromium coating for a solar panel absorber. This research is a primary study at Universiti Teknologi Malaysia which involves the application of thermal energy. The other research such as solar car and solar cycle are concentrated on the photovoltaic system. The research has been conducted to optimise the plating parameters for the black chromium solar selective surface, in order to develop a solar water heater panel set-up.

The research involves two types of black chromium baths, namely fluoride and borate. The work undertaken was to optimise new plating parameters to investigate the performance of the black chromium coating with respect to the

Malaysia climate, which is hot and humid. The optimisation of the black chromium coating is considered a pioneering effort whereby the black chromium coatings are being investigated for the solar thermal energy application instead of decorative and non-decorative purposes. The optimisation of the plating parameters can improve the existing black chromium coating and it can be a driving force in developing a solar water heater panel, which suits the Malaysian environment.

1.2 Research Background

A flat plate collector of a copper substrate electroplated with a thin black chromium solar absorber has been studied for its role and optimisation of the plating parameters such as; plating time, current density, plating bath temperature and the effect of the surface particles overgrowths deposition with respect to the spectral selectivity [absorptance (α) and emittance (ε)] properties. The design of a flat plate collector system is focused on receiving solar radiation so that the coating capable to absorb the highest absorptance in solar spectrum near infrared region (wavelength 0.3 μm to 2.0 μm) and low emittance (wavelength > 2.0 μm).

Eventhough, a lot of work has been carried out in designing and constructing the selective solar absorbers, only few studies have been recorded regarding the plating parameters of the black chromium coating. It has been reviewed (Inal et. al., 1981) that plating geometry such as plating time, plating bath temperature and current density influences the plating parameters. These factors enhance the effect of the black chromium particle growth, and thus the spectral selectivity of the optical properties. Thus, it is important to study the role of the optimisation of the plating parameters in order to obtain the optimum optical properties.

1.3 Brief Introduction of Black Chromium Coating Selective Surface

Solar energy can be utilised both to generate and conserve energy. Various applications of solar energy are such as water heating, crop drying, air heating and solar electric power generation (photovoltaic). Large scale of solar water heater is successfully marketed in Japan, Australia and India (Ong, 1994). As for Malaysia, the development of solar coating materials for solar thermal energy is still at the preliminary stage. A lot of effort has been channelled to improve this area and one of the areas of interest is black chromium coating.

Black finishing applications cover a wide range of area such as for non-reflecting coating, decorative coating and solar selective coating. This work is focused on solar selective coatings where it is used for thermal energy applications, which is targeted for solar water heater. Selective black coatings are used on surfaces of devices meant to collect solar energy for its improvement. The key of an efficient solar absorbing coating is the spectral selectivity. Black chromium selective absorbing solar coatings have made a contribution towards improving the performance of solar energy collectors with high solar absorptance (α) and low emittance (ε) in the solar spectrum near the infrared region. It is used for photothermal conversion in solar collector system of low and moderate concentrations. Black chromium selective absorber has been proved to be the most suitable coating for a wide range of temperature applications due to its excellent optical properties and apparent high degree of stability under the operating conditions (Window et. al., 1980).

Black chromium electrodeposition gives satisfactory finishes where the properties can be concentrated easily by the operating conditions such as plating time, plating bath temperature and current density (Inal et. al., 1981; Driver, 1981). The throwing powers of the compositions are related to the bath solutions. Various researchers have formulated black chromium plating solutions (William, 1975; Clive and John, 1980; Magyar and Pojbics, 1988; William Grips et. al., 1989, 1991), improved and designed new black chromium plating processes (Wilson, 1971; Oleson and Woods, 1973; Kampshchulte and CIE, 1976; Tomoyo and Matsufumi, 1979; Motoaki, 1981; Yasuo, 1982; Itsupei, 1986) and found out that it is a unique black coating where the black coating can be obtained at various bath temperatures and current densities. It is noted that every black chromium solution has its own optimum values with respect to the optical properties. The optical property also depends on the plating process and the plating parameters play an important role in order to achieve the best quality of black chromium coating. It is also reported (William Grips et. al., 1989, 1991) that the black chromium coating has excellent corrosion resistance, high thermal stability and good weather resistance. It can be coated on a copper plate with good adherent film without prior nickel undercoat and this will save a lot of processing time.

For these reasons, a preliminary study on the performance of the black chromium coating is undertaken where it is conducted in the laboratory testing conditions. The study will cover a Hull cell test followed by a simple room temperature electroplating process to produce the black chromium coating, optical test for its spectral selectivity properties, adhesion test, thermal stability test upon high temperature and surface morphology observation.

1.4 Objective and Scope of Study

The objectives of the investigation are to optimise the plating parameters of the black chromium coating applicable on solar energy absorbing materials and to study the performance and its properties upon the author's new improved solutions on copper substrate as a potential solar panel material.

The main part of this study is to investigate the black chromium coating plating parameters that can be used to absorb the solar radiation and conserve it into heat for heating water. The coating should have good optical and mechanical properties as well as humidity, weatherability and corrosion resistance. This is to make sure that the black chromium coating can withsatnd the water heating process.

To produce the black chromium coating, the newly improved fluoride and borate baths are chosen as the plating solution. The addition of 10 g/l of barium carbonate ($BaCO_3$) in the new improved solutions is to precipitate any traces of sulphate which, the results produced an excellent and stable black coating on the copper substrate. These two improved baths act as a comparison study in order to investigate the optimum plating parameters and the performance of the coating. The scope of the research covers:

1. Investigation of the effect of the plating parameters on the coating's optical properties (absorptance > 0.9 and low emittance < 0.35). The operating parameters involved are current density, plating time and bath temperature, which have been identified earlier in the preliminary electroplating process. The deciding plating parameters under investigation are:

   i. 9-17 A/dm^2, 1-7 minutes and 16-32^{0}C for fluoride baths, and
   ii. 16-32 A/dm^2, 3-11 minutes and 16-36^{0}C for borate baths.

2. Study of the effect of humidity, weatherability and corrosion on the optical properties of the coating.

3. Determination of the black chromium coating properties such as the coating adhesion, thickness, surface morphology, crack density and thermal stability.