ISSN: 1411-4348

MECHANICAL PROPERTIES OF Cu SURFACE IN THE LAMINATED STRUCTURE OF Cr-Cu COATINGS

Tri Widodo Besar Riyadi

Faculty of Engineering, Universitas Muhammadiyah Surakarta
Jl. A. Yani Tromol Pos 1 Pabelan Kartasura, Surakarta, Indonesia 57102
Email : Tri.Riyadi@ums.ac.id

ABSTRACT

A laminated structure of Cr-Cu coating was produced by electroplating on a carbon steel substrate. Two baths of chromium and copper electrolyte solutions were prepared to respectively deposit Cr and Cu as the first and second layer. The Cr was plated using the same plating time of 60 minutes, whereas Cu was deposit using plating time of 1 hour, 1.5 hours, 2 hours, 3 hours and 3.5 hours. The effect of plating time on the thickness, hardness and specific wear rate of the Cu surface was investigated. The formed phase, thickness, hardness and specific wear rate of the Cu surface were observed using XRD, optical microscope, Vickers microhardness tester and Ogoshi wear rate tester, respectively. The results show that Cu was formed on the surface. An increase of the Cu plating time increased the thickness and the specific wear rate of the Cu surface, but reduced the hardness of Cu surface. Cu layer was observed denser than that of Cr. This study showed that the use of Cu can be a potential candidate to laminate Cr for use in corrosive environment.

Keywords: Cr-Cu, Plating time, Hardness, Specific wear rate

INTRODUCTION

Hard chromium coatings have long been considered as the most used electrodeposited coatings in several industrial applications such as in petro chemistry, oil and gas industries. This is due to the advantageous properties of chromium coatings such as high hardness, low coefficient of friction, high wear and corrosion resistance [1, 2]. The use of components applying chromium coatings for long storage, as long as million years, in nuclear fuel container, however, requires a property enhancement for corrosion barrier.

In recent years, the use of copper as an exterior coating for corrosion barrier has been considered by several researchers in nuclear waste management [3]. Corrosion may occur by a range of mechanisms such as by localized stress generating cracking, microbial influenced, radiation induced and even atmospheric corrosions. Copper is a well proven corrosion resistance and antimicrobial material which can be used in such corrosive environment. The use of copper as coating can offer a good protection for a touch surface for very long time since it possesses good mechanical properties like scratch resistance and microhardness [4]. Under a maximum shearing stress, a scratch can develop into void or deep crack which subsequently cause a spalling of the coating parts. These damages are unacceptable for component used in corrosive environment since it can lead to the degradation of the mechanical properties of the base metal [5]. Copper is a soft metal which has attracted many attentions for use as under or upper layer of the hard chromium coatings.

Laminating the structures of chromium coating by copper has attracted many attentions because such structures can be used to modify the surface properties [2]. The concept of a chromium-copper coating is very attractive and its development is required to ensure that the process is technologically feasible and meets the requirements of the safety case. It is therefore necessary to conduct extensive experimental works of the coatings to withstand relevant environmental conditions for long periods of time. The objective of this work was to investigate the electroplating process of a laminated structure of Cr-Cu layer on a carbon steel substrate. The effect of plating times on the thickness, hardness and specific wear rate of the product were observed.

EXPERIMENTAL PROCEDURE

The substrate used in the present work was obtained by cutting a long bar of carbon steel ST 40 into a sample with diameter of 16 mm and 3 mm thickness. Preparation stages were carried out prior to electroplating process using grinding by silica papers, polishing and cleaning in an ultrasonic cleaner. Two baths of chrome and copper electrolyte solutions were prepared to deposit Cr and Cu layers, as used in our previous works [6, 7]. The chrome layer was firstly deposited on the steel following by the copper which was subsequently plated as the upper layer. The electrolyte solution used for plating chrome contains chromic acid 250 g/l, sulphuric acid 2.5 g/l, and kalium cyanide KC-15 10 g/l, whereas the electrolyte solution used for copper plating was copper sulphate (20 g/l $CuSO_4$) and aquadest. The plating time of Cr layer were kept constant at 60 minutes, whereas the plating time of copper was varied using 1 hour, 1.5 hours, 2 hours, 3 hours and 3.5 hours.

The identification of the phase formation on the surface of the electroplated products was observed by XRD. The measurement of the thickness of each layer was carried out after the samples were polished using standard metallographic techniques. The cross sectional appearance of the products was recorded using an optical microscope. The hardness measurement of the surface plating, conducted on the Cu surface, was measured using a Vickers microhardness tester (type TTS unlimited HWMMT-X7) with diamond pyramid (136°) using a load of 50 gf and penetration time of 10 second. The mean hardness, its standard deviation and standard error were recorded to the 5 times measurements in arbitrary positions on the Cu surface. The wear test was carried out using Ogoshi high speed universal wear testing machine with a gear ratio of 70/40, a load of 3.18 kg, revolving disc thickness of 3 mm and revolving time of 30 seconds.

RESULTS AND DISCUSSION

Figure 1 shows the XRD pattern scanned on the top surface of the sample. Some observed peaks of the XRD pattern show that only Cu phase was formed on the surface of the sample. There was no Cr phase which can be identified. This indicates that the two steps of electroplating process of Cr and Cu have generated a laminated structure of Cr-Cu instead of a chrome-copper alloy. The sharp peaks detected on the XRD pattern should indicate that the Cu has a crystalline structure.

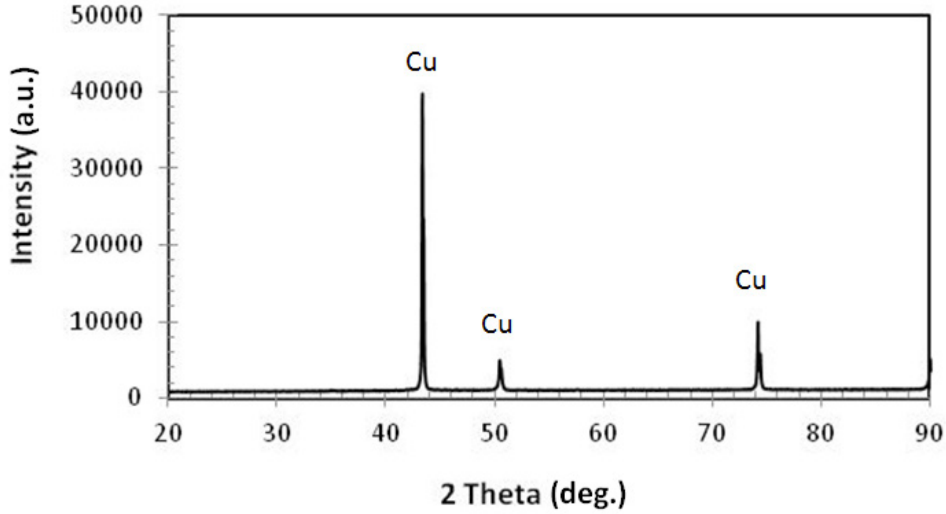

Figure 1. XRD pattern observed on the Cu surface

Figure 2 shows the cross sectional feature obtained by optical microscopes. The figure gives clear evident on the composition of the laminated structure of Cr-Cu and their thicknesses. The steel substrate was in grey colour, the chromium layer was in black one, and the copper located at the upper layer was in bright colour. Since the experimental work was carried out to produce a laminated structure of Cr-Cu with different plating time of Cu deposition, their thickness was varied. Figure 3 shows the thickness of Cr and Cu, where Cr layer in all samples was deposited using 60 minutes, whereas the Cu layer in the sample 1,2,3,4 and 5 was deposited using different plating times of 1 hour, 1.5 hours, 2 hours, 3 hours and 3.5 hours. The result shows that the thickness of chromium layer which was deposited using the same plating time of 60 minutes was almost the same in the range of 36.7 to 44.7 μm. A little discrepancy of the Cr thickness might be caused by uncertainty of the measurement location due to the unevenness layer produced by electroplating. Whereas, the thickness of Cu layer measured on five samples with different plating times indicates that an increase of Cu plating time has linearly increased the thickness of Cu from 48.1 to 74.3 μm. Comparing the morphology of the Cr and Cu layer observed from the figure, it can be shown that Cu layer is much denser than that of Cr. The use of a dense structure for the corrosive environment is much acceptable since the layer can halt the infiltration of gas from its atmosphere.

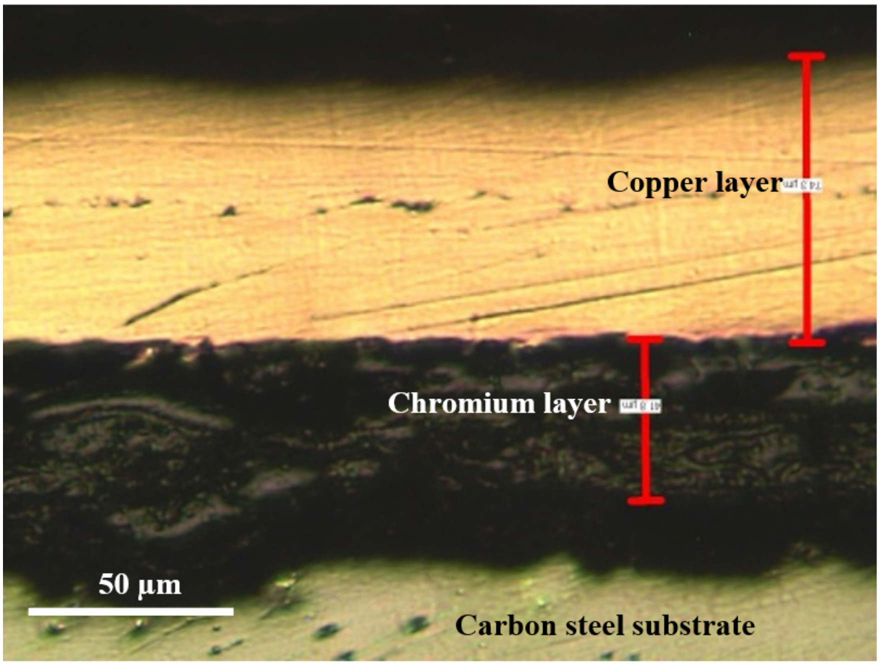

Figure 2. Cross section of Cr and Cu layer in the laminated Cr-Cu coatings

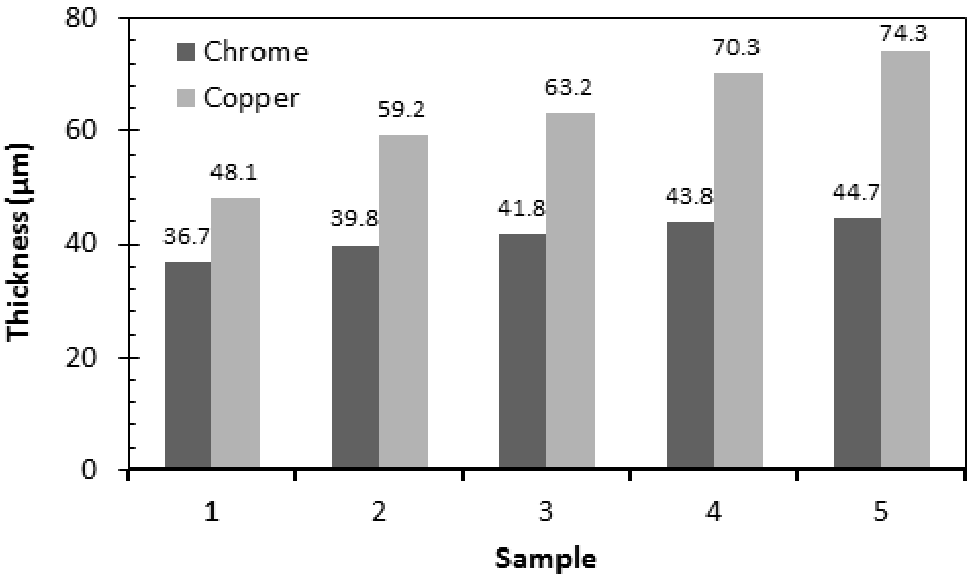

Figure 3. Thickness of Cr-Cu layers: all Cr plated by 60 minutes, Cu plated by (1) 1 hour, (2) 1.5 hours, (3) 2 hours, (4) 3 hours, (5) 3.5 hours

Figure 4 shows the microhardness of the Cu deposit with respect to the plating times. The result shows that the mean hardness of the plated Cu decreased significantly from 126.13 to 58.40 HV as the increase of the plating time from 1 to 3.5 hours. The increase of the plating time from 1 to 1.5 hours has sharply decreased the hardness of Cu surface from 126.13 to 87.40 HV. However, the hardness of Cu surface stayed in a plateau with an increase of plating time from 2 to 3 hours. Further increase of the plating time reduced the hardness of Cu. The decrease of the Cu hardness indicates that the internal stress in the Cu layers gets lower. Since the measurement of the hardness was conducted on the surface, the decrease of Cu hardness was also attributed to the reduced influence of the chrome hardness which located below the Cu layer. In all samples, the hardness of Cu layer was much lower than that of the chrome layer, where the chrome hardness obtained by our previous study was 181.1 HV in average. This indicates that the internal stress in the Cu plating is lower than that of the Cr layer. A decrease of an internal stress is benefit to avoid the possibility of crack generation resulting in a better corrosion resistance during its long operation.

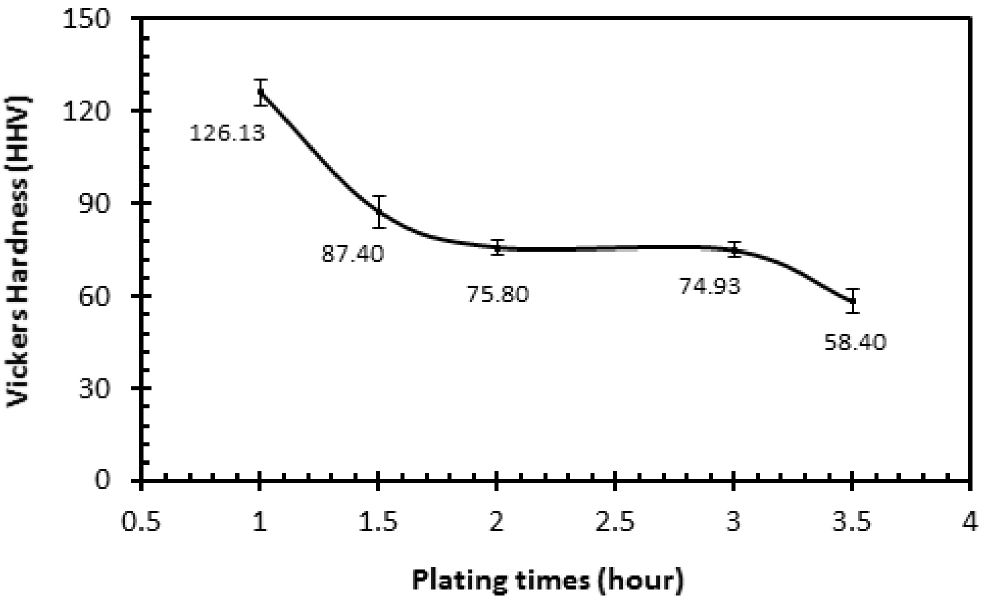

Figure 4. Hardness measured on Cu surface in the laminated Cr- Cu coatings with respect to Cu plating times

Figure 5 shows the specific wear rate observed on the Cu layer deposited using different plating times of 1 hour, 1.5 hours, 2 hours, 3 hours and 3.5 hours. The result of the wear test shows that the specific wear rate increased nearly linearly from 3.33 x 10-4 to 4.8 x 10-4 mm^3/kg.m as the increase of the plating times from 1 hour to 3.5 hours. The result of this study indicates that the wear volume of the Cu surface increased as the increase of the Cu thickness. This might be related to the reduced hardness of the surface as the increase of the plating time. The wear resistance of the Cu surface therefore reduced with the increase of the plating times, as also occurred with the hardness of the Cu surface.

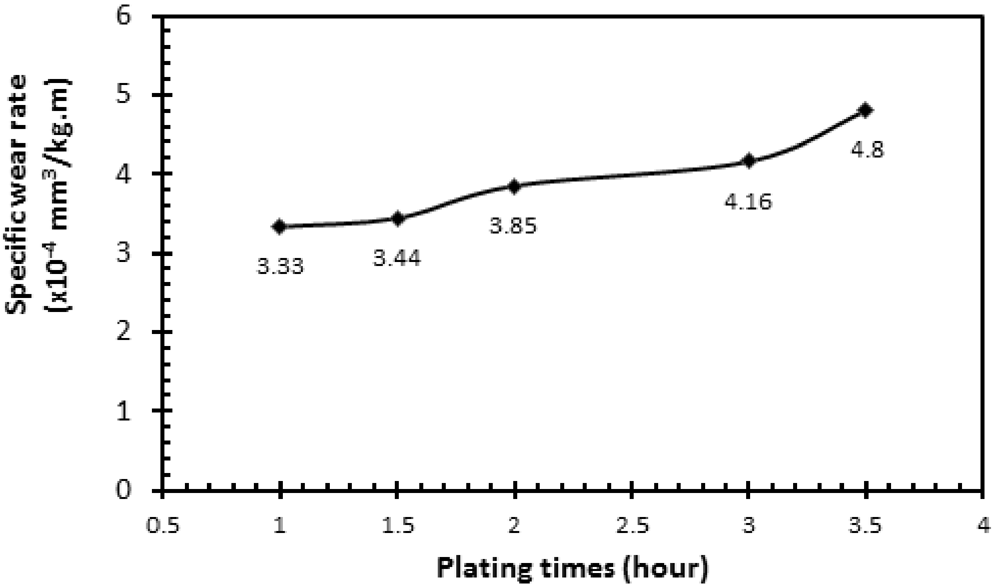

Figure 5. Specific wear rate observed on Cu surface in the laminated Cr-Cu coatings

CONCLUSIONS

A laminated structure of Cr-Cu was successfully deposited using electroplating process with the same plating time of Cr and different plating times of Cu. The formation of Cu layer in the upper layer was confirmed by XRD test. The micrograph observed on the cross sectional area of the samples showed that an increase in the Cu plating times increased the thickness of Cu layer. The thickness increase of Cu layer produced a decrease in the hardness and an increase of the specific wear rate of the Cu surface. A dense structure accompanied by a decrease of the Cu hardness offered good corrosion resistance coatings.

ACKNOWLEDGMENTS

The authors would like to thank the '*Direktorat Riset dan Pengabdian Masyarakat* (DRPM)', the ministry of research and technology for higher education (Kemenristekdikti), the Government of Indonesia, and LPPM Universitas Muhammadiyah Surakarta for supporting the research funding. Special thanks would also dedicate to my student Yusuf Nur Afandi who has spent much of his time to help some experimental works.

REFERENCES

[1] Ching An Huang, Chao Yu Che. *Hardness variation and annealing behavior of a Cr–Ni multilayer electroplated in a trivalent chromium-based bath.*, Surface & Coatings Technology, pp. 203, 3320–3324, 2009.

[2] Ching An Huang, Chao Yu Chen, Chun Ching Hsua and Chao Sung Lin. *Characterization of Cr–Ni multilayers electroplated from a chromium(III)–nickel(II) bath using pulse current.*, Scripta Materialia, pp. 57, 61–64, 2007.

[3] P. G. Keech, P. Vo, S. Ramamurthy, J. Chen, R. Jacklin and D. W. Shoesmith, *Design and development of copper coatings for long term storage of used nuclear fuel*, Corrosion Engineering, Science and Technology, Vol. 49 No. 6, pp. 425-430, 2014.

[4] Jiaping Zhang, Xiaomei Feng, Yifu Shen, Cheng Chen, and Cuiyuan Duan, *Microstructures and properties of Cr–Cu/W–Cu bi-layer composite coatings prepared*

by mechanical alloying, International Journal of Materials Research 107, 6, 544-552, 2016.

[5] E. Menthe, K. T. Rie, *Plasma nitriding and plasma nitrocarburizing of electroplated hard chromium to increase the wear and the corrosion properties*, Surface and Coatings Technology, pp. 112, 217–220, 1999.

[6] Masyrukan, Tri Widodo Besar Riyadi, Bibit Sugito, dan Yudit Novianto, *Effect of Immersion Time on the Deffect Formations and Properties of the Electroplating Chrome*, Proceeding of The 2nd International Conference on Engineering Technology and Industrial Application (ICETIA 2015), Engineering for Creative Industry, page 111-115, 15 Oktober 2015.

[7] Tri Widodo Besar Riyadi, Masyrukan, Bibit Sugito, dan Tri Widodo, *Pengaruh Waktu Tahan Celup Terhadap Nilai Kilap dan Ketebalan Lapisan Tembaga pada Proses Elektroplanting Baja Karbon Tinggi*, Media Mesin, Vol. 15 No. 2 hal. 87-92, Juli 2014.