Modern Technologies for Engineering, Applied Mechanics and Material Science

Edited by
Debnath Sujan and Reddy M. Mohan

TTP TRANS TECH PUBLICATIONS

Modern Technologies for Engineering, Applied Mechanics and Material Science

Selected, peer reviewed papers from the
5th International Conference on
Manufacturing Science and Technology
(ICMST 2014),
June 7-8, 2014, Sarawak, Malaysia

Edited by

Debnath Sujan and Reddy M. Mohan

Trans Tech Publications Ltd
Churerstrasse 20
CH-8808 Pfaffikon
Switzerland
http://www.ttp.net

Volume 980 of
Advanced Materials Research
ISSN print 1022-6680
ISSN cd 1022-6680
ISSN web 1662-8985

Full text available online at *http://www.scientific.net*

***Distributed** worldwide by*
Trans Tech Publications Ltd
Churerstrasse 20
CH-8808 Pfaffikon
Switzerland

Fax: +41 (44) 922 10 33
e-mail: sales@ttp.net

and in the Americas by
Trans Tech Publications Inc.
PO Box 699, May Street
Enfield, NH 03748
USA

Phone: +1 (603) 632-7377
Fax: +1 (603) 632-5611
e-mail: sales-usa@ttp.net

printed in Germany

Modern Technologies for Engineering, Applied Mechanics and Material Science

Edited by
Debnath Sujan
Reddy M. Mohan

Preface

2014 5th International Conference on Manufacturing Science and Technology (ICMST 2014) was held in Sarawak, Malaysia on 7-8, June, 2014. The conference provides a platform to discuss Manufacturing Science and Technology etc. with participants from all over the world, both from academia and from industry. Its success is reflected in the papers received, with participants coming from several countries, allowing a real multinational multicultural exchange of experiences and ideas.

The present volumes collect accepted papers and represent an interesting output of this conference. This book covers these topics: Acoustics and Noise Control, Aerodynamics, Applied Mechanics, Automation, Mechatronics and Robotics, Automobiles, Automotive Engineering, Ballistics, Biomechanics, Biomedical Engineering, CAD/CAM/CIM, CFD, Composite and Smart Materials, Compressible Flows, Computational Mechanics, Computational Techniques, Dynamics and Vibration, Energy Engineering and Management, Engineering Materials, Fatigue and Fracture, Fluid Dynamics, Fluid Mechanics and Machinery, Fracture, Fuels and Combustion, General mechanics, Geomechanics, Health and Safety, Heat and Mass Transfer, HVAC, Instrumentation and Control, Internal Combustion Engines, Machinery and Machine Design, Manufacturing and Production Processes, Marine System Design, Material Engineering, Material Science and Processing, Mechanical Design, Mechanical Power Engineering, Mechatronics, MEMS and Nano Technology, Multibody Dynamics, Nanomaterial Engineering, New and Renewable Energy, Noise and Vibration, Noise Control, Non-destructive Evaluation, Nonlinear Dynamics, Oil and Gas Exploration, Operations Management, PC guided design and manufacture, Plasticity Mechanics, Pollution and Environmental Engineering, Precision mechanics, Mechatronics, Production Technology, Quality assurance and environment protection, Resistance and Propulsion, Robotic Automation and Control, Solid Mechanics, Structural Dynamics, System Dynamics and Simulation, Textile and Leather Technology, Transport Phenomena, Tribology, Turbulence and Vibrations.

This conference can only succeed as a team effort, so the editors want to thank the international scientific committee and the reviewers for their excellent work in reviewing the papers as well as their invaluable input and advice.

Prof. Dr. Ashutosh Kumar Singh
Department of Computer Application
National Institute of Technology
Kurukshetra, India

Committees

Conference Chairs

Prof. Dr. Ashutosh Kumar Singh, Department of Computer Application, National Institute of Technology, Kurukshetra, India

Program Co-Chairs

Dr. Sujan Debnath, Curtin University, Sarawak, Malaysia

Dr. Moola Mohan Reddy, Curtin University, Sarawak Malaysia

Technical Committee

Prof. Nordin Abu Bakar, Faculty of Computer &Mathematical Sciences, Universiti Teknologi MARA, Malaysia

Prof. P. Sivaprakash, A. S. L. Pauls College of Engineering& Technology, India

Nardinocchi Alessandro, Università Politecnica delle Marche, Ancona, Italy

Dr. Wan Hasrulnizzam Wan Mahmood, Universiti Teknikal Malaysia, Malaysia

Dr. Hwa JenYAP, Faculty of Engineering, University of Malaya, Malaysia

Prof. Yusri Yusof, Universiti Teknologi Tun Hussein Onn, Malaysia

Dr. S. K. Singh, India Gokaraju Rangaraju Institute of Engineering and Technology

Prof. Alexander Gorin, Swinburne University, Sarawak, Malaysia

Prof. Khaled Abou Hossein, Nelson Mandela Metropolitan University, South Africa

Dr. Nazrul Islam, Curtin University, Australia

Dr. Brian Bosewell, Curtin University, Australia

Dr. Rajaram Ganesan, National Engineering Industries Ltd. Jaipur, India

Dr. Rajamohan Ganesan, Curtin University, Sarawak, Malaysia

Dr. Vincent Lee Chieng Chen, Curtin University, Sarawak, Malaysia

Prof. Jamaluddin Mahmud, Universiti Teknologi Mara (UiTM), Malaysia

Sponsors

Curtin University of Technology, Sarawak Campus, Malaysia

Table of Contents

Preface v
Committees and Sponsors vi

Chapter 1: Advanced Materials Engineering and Technological Processes

Properties and Growth Rate of Intermetallic Al-Fe through Hot Dipped Aluminizing
Z. Samsu, N.K. Othman, A.R. Daud and M. Daud 3

Performance Evaluations of Carbon/Glass Hybrid Polymer Composites
C.L. Tan, A.I. Azmi and N. Mohamad 8

Bioactivity Behavior of YSZ-Al$_2$O$_3$/10HAP Bioceramics Composites in Simulated Body Fluid
M.R.N. Liyana, N.M.S. Adzali and M.Z.M. Zamzuri 13

Water Absorbency Properties of OPEFB Filled Hydrogels Composites
N.E. Rabat, S. Hashim and R.A. Majid 18

Oil Palm Fibre and Nano-Silica Reinforced Epoxy Composite Material
N. Samuel, D. Sujan, M.E. Rahman, O. Nabinejad and M.M. Reddy 23

Preparation and Dimensional Stability of Organo-Montmorillonite (O-MMT) Treated Unsaturated Polyester Hybrid Composites Filled with Keratin Fiber
K.K. Siong, S.K. Heng, S. Hamdan, M. Mohsin, A. Kakar and M. Hameed 28

A Critical Survey of Ceramics Materials for Production of Automotive Engine Block
P.B. Mogaji, T. Jamiru, D. Desai and R. Sadiku 33

Optical Properties of Gallium Nitride Heterostructures Grown on Silicon for Waveguiding Application
I. Saraswati, A. Stolz, S. Ko, E. Dogheche, N.R. Poespawati, R. Wigajatri and D. Decoster 41

Effect of Austenizing and Tempering Time on Corrosion Rate of Austenitic Stainless Steel in Oxalic Acid
M.A. Gebril, M.S. Aldlemey, F.I. Haider and N. Ali 46

Analysis of Thickness Strain Prediction in Warm Deep Drawing of Ti-6Al-4V Alloy
N. Kotkunde, A.D. Deole, A.K. Gupta and S.K. Singh 52

Evaluation of CO$_2$ Uptake under Mild Accelerated Carbonation Conditions in Cement-Based and Lime-Based Mortars
C. Furcas, G. Balletto, S. Naitza and A. Mazzella 57

A Breif Review on Manufacturing of Al-TiC MMC
S.K. Josyula and N.S.K. Reddy 62

The Investigation of Microstructures Fabrication on Quartz Substrate Employing Electron Beam Lithography (EBL) and ICP-RIE Process
L. Shamsuddin, K. Mohamed and A.R. Maryam 69

Potential of Clay Deposits in Kelantan for Ceramic Production: A Literature Analysis
O.F. Enoch, A.A. Shuaib and K.A.B.M. Daud 74

Chapter 2: Applied Mechanics and its Applications in Civil Engineering

Finite Element Prediction of Mechanical Behaviour under Bending of Honeycomb Sandwich Panels
K. Sid-Ali, M. Amar, S. Boutaleb and K. Azouaoui 81

The Effect of Alkali Treatment of OPKS Filler on Mechanical Property of Polyester-Composite
O. Nabinejad, D. Sujan, M.E. Rahman, M.M. Reddy, W.Y.H. Liew and I.J. Davies 86

Effect of Curing Age on the Compressive Strength of Petrovege Blocks
O.A. Johnson, N. Madzlan and I.B. Kamaruddin 91

Evaluation of Spur Gear Pair on Tooth Root Bending Stress in Yawing Misalignment Contact Condition
M.R. Lias, M. Awang, T.V.V.L.N. Rao and M. Fadhil 97

The Effect of Morphing Force on Aerodynamic Performances of TM Wing
N.I. Ismail, A.H. Zulkifli, M.Z. Abdullah, M.H. Basri and M.M. Mahadzir 102

Analysis of Concurrent Brake Application for Underbone Motorcycle
M.H. Basri, A.H. Zulkifli, N.I. Ismail, S. Che Mat and M.M. Mahadzir 107

The Three-Dimensional Unsteady Numerical Analysis of the Internal Flow Field of the New Control Valve
D.Y. Qu, J.L. Xu, Y.Y. Huang and X.Z. Xie 112

Determination of Nozzle Angle for Flow Performance in Supersonic Subsea Compact Wet Gas Separator
F.M. Mohd Hashim and M.F.A. Ahmad 117

Identification of the Mechanical Properties of High-Strength Steel Using Digital Image Correlation
M. Štamborská, M. Kvíčala and M. Losertová 122

Comparison of the Stress-Strain Behaviour of Cast TiAl6V4, Porous TiAl6V4 and Cortical Bone during the Mechanical Load Caused by Common Daily Activities
M. Kvíčala, M. Štamborská and J. Drápala 127

Development of Splice Connections for Precast Concrete Structures
A.B.A. Rahman, J.H. Ling, Z.A. Hamid, M.H. Osman, S. Mohammad and A.A. Saim 132

Study of Ultra High Performance Fiber Reinforced Concrete with Expansive and Shrinkage Reducing Agents
A. Nardinocchi and V. Corinaldesi 137

Lightweight Aggregate Mortars for Sustainable and Energy-Efficient Building
V. Corinaldesi, A. Nardinocchi and J. Donnini 142

Study on Damage Modes of a Sandwich Panel Impacted Repeatedly
K. Azouaoui and S. Mouhoubi 147

Micromechanical Model Prediction Overall Young Modulus Nanocomposites Polymer-Clay-Silica by Self Consistent Approach
A. Mesbah, K. Azouaoui, S.A. Kaoua and S. Boutaleb 152

Chapter 3: Modern Technologies for Modelling, Simulation and Automation, Instrumentation, Measurement and Control Technologies

A Method of Determining the Direction of Two Dimensional Curves
F. Wang, R.K.F. Abdelmaguid and H.M.A. Hussein 159

Implementation of a Voice-ControlSystem for Issuing Commands in a Virtual Manufacturing Simulation Process
Y.S. Pai, H.J. Yap and S. Ramesh 165

Non-Zero Multi-Valued Decision Diagram (NZMDD) Based Synthesis of Multi-Valued Logic (MVL) Functions
A.K. Chowdhury, N. Raj and A.K. Singh 172

Developing a Solar Calculator System
S. Muhammad-Sukki, M.T.K.M.N. Khan, A.M. Zeki, A. Abubakar and F. Muhammad-Sukki 179

ISO 6983 Translator for PC Based CNC Systems
Y. Yusof and K. Latif 184

On the Proportionality of Damage Rule in Finite Element Simulations of the Ductile Failure
F. Šebek, J. Hůlka, P. Kubík and J. Petruška 189

New Algorithm to Reduce File Size and Bandwidth of Hashed Digital Signature for Image Steganography Using LSB
E. Noroozi, S.B.M. Daud, A. Sabouhi and M.R. Salehnamadi 194

Simulation Optimization – Testing Selected Optimization Methods and their Setting of the Parameters
P. Raska and U. Zdenek 198

Characterization of Diamond Electrodeposited Tool for Vibration Assisted Grinding Diagnostic
M.F. Ismail 203

If-Then Rules for Selection the Die-Set for Sheet Metal Punching and Blanking Dies
H.M.A. Hussein, J.A. Qudeiri, U. Umer and R.K. Abdel-Magied 208

Adaptive GA-NN for MDF Prediction Model
S.I. Faridah and A.B. Nordin 214

New Model for Knock Factors Optimization in Internal Combustion Engine (SI)
A.R.H. Witwit, A. Yasin, H. Gitano and T.K. Yadav 219

RFID Secure Protocol Based on Time-Based Hash Chain
C. Lin, S.F. Zhao and S.P. Chen 225

A Novel Manufacturing Chain for Low Cost 3D Textile Reinforced Polymer Composites
A. Almansa, M. Fazeli, B. Laurent, P. Padros and M. Hörlesberger 230

Chapter 4: Product Design and Development, Industrial Engineering

Multi-Echelon Production System Planning: Case Study at a Steel Company in Indonesia
R. Govindaraju and R.A.R. Hariadi 237

Research – Design & Development of Fast Customized Manufacturing for Prostheses TKR Based on Rapid Prototyping
A. Suwandi, G. Kiswanto, W. Kusumaningsih and T.P. Soemardi 243

Manufacturing Execution System Design Using ISA-95
R. Govindaraju, K. Lukman and D.R. Chandra 248

A Vide Survey on Product Development and Commercialization Process
R.R. Salman, Y.A.A. Hammouda, S. Monsef and M. Sadeghi 253

Basic Approaches to Green Production of Board Wood Composite Materials
V.P. Tishchenko, L.P. Mayorova and O.M. Morina 258

Design and Analysis of Automotive Instrument Panel
N.A. Haniffah, M.F. Zakaria and T.K. Sheng 263

Keyword Index 269

Author Index 273

CHAPTER 1:

Advanced Materials Engineering and Technological Processes

Advanced Materials Research Vol. 980 (2014) pp 3-7
© (2014) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/AMR.980.3

Properties and Growth Rate of Intermetallic Al-Fe Through Hot Dipped Aluminizing

Zaifol Samsu[1, 2, a], Norinsan Kamil Othman[1, b], Abd Razak Daud[1], Muhammad Daud[2, c],

[1]School of Applied Physics, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

[2]Material Technology Group, Industrial Technology Division, Malaysian Nuclear Agency, 43600 Bangi, Selangor, Malaysia

zaifolsamsu@nuclearmalaysia.gov.my[a], insan@ukm.my[b], mdaud@nuclearmalaysia.gov.my[c]

Keywords: Hot Dipped Aluminizing. Finger-Like. Hardness.

Abstract. Hot dipped aluminizing is the one of the most famous and effective method of the surface protection. The growth behavior in the intermetallic layer by introducing a different dipping time and various of molten aluminium temperature had been detail investigated. The result showed that the top portion of the coated steel substrate is compose of a thin layer of α- Al_2O_3, followed by thicker Aluminium pure layer, thinner layer of $FeAl_3$, and then a much thicker of Fe_2Al_5 . The intermetallic layer is 'thick' and exhibits a finger-like growth into the steel. The thickness of Al-Fe intermetallic layer on the steel base is increased with the increasing of hot dipping temperature and time. The micro hardness testing result shown that increasing of the aluminizing temperature was increased the hardness of the intermetallic layer.

Introduction

Hot dipped aluminizing process has been widely used for protection of carbon steel in high temperature application. The process involves dipping of steel sheet into molten aluminium or its alloy, at a fixed temperature for a certain period of time. The microstructure of the protective coating on the hot-dipped aluminide steel is composed of an outer aluminum topcoat containing the same composition as the aluminum bath and an Fe–Al intermetallic layer formed by Fe/Al inter-diffusion during the hot-dip process. Shigeaki Kobayashi and Takao Yakou [1] showed that the coating layers of hot dip aluminized steel consist mainly of aluminum and Fe_2Al_5 . Aluminized steel exhibit excellent oxidation and corrosion resistance [2].

It was reported [3,4,5] that composition of aluminizing metal and carbon content of steel substrate and its dipping time intensely affect the growth rate of the intermetallic layer, but aluminizing temperature [6] of the substrate does not affect it significantly. Since, previously the effect of the aluminizing temperature on the growth rate of the intermetallic layer was examined in a very short range 775–850 °C [6] and most of the researchers conducted hot-dipping tests above 750 °C in pure Al and Al–Si alloys [7]. As a result, they concluded that aluminizing temperature does not affect the growth rate of intermetallic layer.

Then, the study of aluminizing was re examined by extending the temperature range between 675°C and 950°C of was conducted with width range of aluminizing temperature. It was reported that the growth intermetallic layer was increased for the aluminizing temperature in the range 675°C-775°C but the thickness did not increase further when the aluminizing temperature increased in the range 775°C–950°C [8]. However, the results of the present study were found different from the preceding one. This study reveal that the variation in the aluminizing temperature and dipping time have a profound effect on the growth kinetics and hardness of the intermetallic layer

Experimental

Material and Method. A commercial AISI 1005 steel was used as the substrate material in this study. The chemical composition of the adopted steel is Fe-0.047C-0.137Mn-0.035P-0.01S (%wt).

Rectangular specimen with dimension of 20mm x 10mm x 2mm was cut using a water cooled cutting machine. Laboratory grade pure aluminium with a purity of 99.9% was used as the molten aluminium bath. The surfaces of the steel specimens for aluminizing were finished by grinding with a #1000 SiC paper. Then the specimen was degreased in acetone and finally cleaned ultrasonically in acetone. A hole of its diameter approximately 3mm was drilled at one end of the specimen to facilitate its hanging into molten aluminium.

Hot Dipping. The aluminium granular was heated to the temperatures of range between 700°C until 850°C in a graphite crucible using a resistance furnace. The temperature of the molten aluminium bath was controlled to be within ±10°C. The specimen was dipped in the molten aluminium for the time period of 3 min until 9 min. These temperatures were maintain throughout the required range of dipping time and were controlled by using a K-type thermocouple. The specimens were gently shaken inside the bath to ensure good wet ability. After dipping for the specified duration, the specimens were withdrawn and cooled in air. These test were conducted to examine the effect of varying aluminizing temperature and dipping time on the growth and morphology of intermetallic layer

Micro Hardness Measurement. Micro-hardness of the aluminised sample was also measured with a Vickers micro hardometer (Shimadzu HMV 2000). The hardness test was performed under an indentation load of 25gf for 10s. Analysis points were spaced so that to eliminate the effect of neighbouring indentations. The sample was separate with the three layers consist of aluminium layer, intermetallic layer and substrate layer. The micro hardness was evaluated by taking ten indentations on each layer and was averaged.

Analysis of Samples. The aluminized specimens were sectioned carefully with a slow water cooled cutting machine. For microstructure observation and analysis, the specimen was carefully mounted, ground and polished to protect the edges. The specimen was etched with a 2% Nital solution to reveal the coating layer microstructure. The thickness of the layer was then measured at least five times at different places on the section.

Analysis of the chemical composition of substrate was performed using spark emission spectroscopy. The microstructures of the aluminized specimens were examined by using an optical microscope. Scanning electron microscope (SEM) attached with EDX (energy dispersive X-ray) facility was employed to analyze elemental concentration of the phases formed in the outer coating and in the intermetallic layer. X-ray diffraction (XRD) technique was also used to identify the phases formed in the outer coating as well as in the intermetallic layer.

Result and Discussion

The Growth of Intermetallic Layer During Hot Dipping. Cross sectional micrograph of mild steel hot dipped in pure Al in Fig. 1. The analysis of the microstructure and composition of the specimen shown that the diffusion layer are divided into three major layer that consist of aluminium layer, intermetallic layer and substrate. The aluminide layer is composed of an outer aluminium topcoat and an inner Fe-Al intermetallic layer. This suggested that the formation of the aluminide layer was mainly due to the outward diffusion of iron, while the inward diffusion of Al contributed to the growth of the aluminide layer.

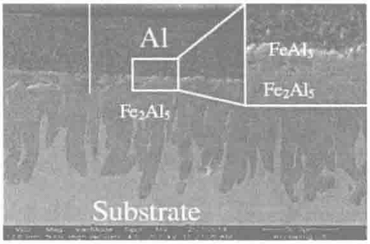

Fig. 1. SEM Micrographs of cross section of specimens after aluminizing

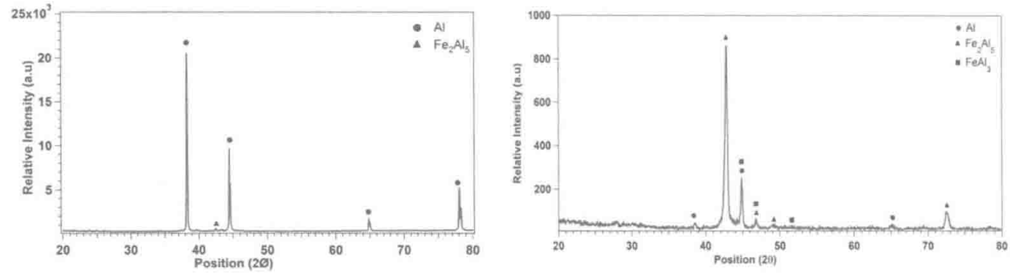

Fig. 2. X ray diffraction pattern of a specimen aluminized in Al pure melt obtained from (a) the outer coating and (b) intermetallic layer

X-ray diffraction analysis confirmed the presence of the phases identified by the scanning electron microscopy in the outer coating as well as in the intermetallic layer. The XRD pattern illustrates the phases formed in the outer coating of the steel specimen aluminized in the Al pure melt as given in Fig. 2(a). The diffraction pattern in the intermetallic layer shows the presence of thin layer of $FeAl_3$ and thick layer of Fe_2Al_5 layer as shown in Fig 2(b). It means that intermetallic layer of Fe_2Al_5 was a major layer for protection of steel after aluminizing.

Fig. 3 and 4 illustrate the different micrograph of the variation in the aluminizing temperature and dipping time on the growth and the morphology of the intermetallic layer respectively. These depict that with increasing the aluminizing temperature of the specimen in the range 700 – 850, the intermetallic layer increased as shown in graphical Fig. 3. The same situations are happen when the dipping time of the aluminizing increased and as a result the intermetallic layer also increased as shown in graphical Fig. 4. These micrograph shown that the pattern growth was changing when the aluminizing temperature and dipping time were increased.

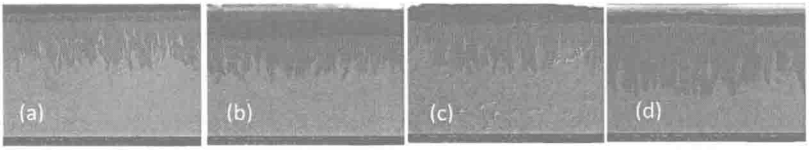

Fig. 3. Cross sectional view of aluminized carbon steel sheets which were hot dipped in melt pure Al at different temperature (a) 700°C (b) 750°C (c) 800°C (d) 850°C

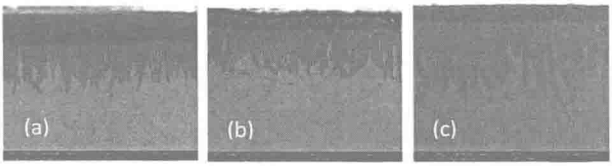

Fig. 4. Cross sectional view of aluminized carbon steel sheets which were hot dipped in melt pure Al at 750°C with various dipping time (a) 3 min (b) 6 min (c) 9 min

Based on the characterization of microstructure (Fig. 1) and phase constitution (Fig 2(b) in the intermetallic layer, the tongue-like morphology of the Fe_2Al_5 phase is formed by the non-uniform growth of the columnar grains.

In the hot dipping process, the specimen dipped in the molten aluminum bath and the steel substrate started to dissolve into the molten aluminum bath . As a result, molten aluminium was diffused into the steel substrate to form an Fe–Al intermetallic layer. The crystalline defects of Fe_2Al_5 with the orthorhombic structure offered a rapid diffusion path to increase the growth rate of Fe_2Al_5 [7], resulting in columnar Fe_2Al_5 and the corresponding residual steel substrate. As the immersion time increased, the columnar grains grew at a fast rate toward the steel substrate, whereas they grew at a slow rate in the lateral direction of the columnar grains. Finally, the consumption of the outer residual steel substrate due to the growth of the columnar $FeAl_3$ + Fe_2Al_5 caused the tongue-like morphology. Moreover, the slow lateral growth of the columnar Fe_2Al_5 provided a pathway for the formation of crystal nuclei of Fe_2Al_5 in the lateral direction, resulting in fine grains clustered in a strip-shaped form around the peaks of the serration-like steel substrate, the original locations of the outer residual steel substrate.

The gradual increase in thickness of the intermetallic layer lead to the possibility that the phases of the steel substrate like ferrite, pearlite and austenite might have affected its growth rate. These phases could have appeared at the outer skin of the steel substrate during the hot-dip aluminizing process at a particular temperature or in a range of temperatures.. As a result the increasing of the intermetallic layer at a range of temperature was due to the ferrite phase for the rapid growth of the intermetallic layer, while both the pearlite and the austenite hampered the growth of the intermetallic layer. As long as the ferrite was present with the pearlite or the austenite in the range of temperature, there was some increase in the intermetallic layer positively.

Micro hardness Analysis. Fig. 5 summarize graphically the effect of aluminizing temperature and dipping time to the hardness of the specimens. The trend of the graph shown that the hardness of the intermetallic layer was increase with increasing the aluminizing temperature. the changes of hardness were come after aluminizing temperature reach to the 800°C and above. The gradual increase of intermetallic layer hardness lead to the possibility that the phase have ferrite, pealite and more austenite during aluminizing process. There were no significant effect to the hardness of aluminium and steel layer.

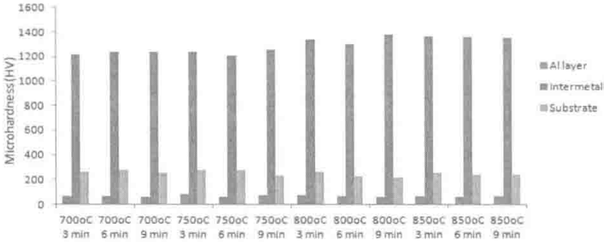

Fig. 5. Microhardness measurement in the cross section of the sample after aluminising at different aluminizing temperature and various of dipping time.

Conclusion

The growth of the intermetallic layer formed in aluminide mild steel by different aluminizing temperature and various of dipping time has been characterized. SEM micrograph shown that the tongue-like morphology of Fe_2Al_5 observed from the cross section of the specimen. The thickness of the intermetallic was increased when increasing the dipping time at various aluminizing temperature. XRD studies shown that the formation of the intermetallic phase for all specimens. The inter metallic layer consisted of thin layer of $FeAl_3$ and thick layer Fe_2Al_5 layer. The crystalline defects of Fe_2Al_5 along the diffusion direction causing Fe_2Al_5 to grow at a rapid rate, resulting in columnar Fe_2Al_5 and corresponding residual steel substrate. The columnar Fe_2Al_5 had a fast growth rate along the diffusion direction, but it grew slowly in the lateral direction of the columns. Microhardness testing shown that the specimen become more harden and probably brittle when the aluminizing temperature was increased.

Acknowledgement

The author would like to thank to all the colleagues from Universiti Kebangsaan Malaysia and a staff from Malaysian Nuclear Agency for assistance and guideline.

References

[1] S. Kobayashi, T.Yakou, Control of intermetallic compound layers at interface between steel and aluminum by diffusion-treatment, Mater Sci Eng A. 338 (2002) 44.

[2] O.N. Mohanty, A. Bahadur, Structural studies of calorized coatings on mild steel. Mater Trans, JIM 31.11 (1990) 948-953.

[3] S.H. Hwang, J.H. Song, Y.S. Kim, Effect of carbon content of carbon steel on its dissolution into a molten aluminum alloy, Mater Science Engineering A 390.1 (2005) 437-443.

[4] M. Yousaf, I. Javed, A. Rafiq, I. Amir, The role of Cu additions in Al on the properties of hot-dip-aluminized steel, J Qual Technol Management 6 (2010) 149.

[5] T. Shih, T. Shu Hao, Interaction of steel with the pure Al, Al–7Si and A356 alloy, Mater Sci Eng A. 349 (2007) 454-455.

[6] M.V. Akdeniz, A. Mekhrabov, The effect of substitutional impurities on the evolution of Fe–Al diffusion layer. Acta Mater. 46 (1998) 1185.

[7] M.V. Akdeniz, A. Mekhrabov, T. Yilmaz, The role of Si addition on the interfacial interaction in Fe–Al diffusion layer, Scr Metall Mater. 31 (1994) 1723.

[8] C. Wang, S. Ming Chen, The high temperature oxidation behavior of hot-dipping Al–Si coating on low carbon steel, Surf Coat Tech. 200 (2006)6601.