UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

HARDFACING PROCESS OF NI-WC ON GRAY CAST IRON SUBSTRATE USING GMAW METHOD

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Science
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DECLARATION

I declare that this thesis entitled "Hardfacing Process of Ni-WC on Gray Cast Iron Substrate Using GMAW Method" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature	:	…………………………
Supervisor Name	:	…………………………
Date	:	…………………………

DEDICATION

To my beloved mother and father.

Thank you for your support and encouragement.

May God bless all of us. InsyaAllah.

ABSTRACT

Hardfacing process of nickel-tungsten carbide (Ni-WC) overlay using gas metal arc welding (GMAW) method has been applied on gray cast iron substrate and the effect on microstructure, macrostructure and hardness property of the deposited overlay has been investigated. In the automotive industry, burr formation defect is continuously occurred on the produced blanks of sheet metal shearing process caused by the wear of the trim cutter die. The problem is more profound when using gray cast iron die which possess low hardness property. Ni-WC is a very hard hardfacing material and has potential to be utilized as the hardfacing material on the gray cast iron die. The use of GMAW method for the purpose of the hardfacing process needs to be done attentively in the aspect of the heat input because the produced heat input of the process affects the microstructure of the overlay thus affecting the hardness property of the hardfacing overlay. The effect of process parameters on the hardness and microstructure of the overlay was studied because the parameters are related to the heat input of the process. The effect of process parameters on the overlay bead width and height was also studied because bead width and height are two of important aspects of a hardfacing overlay. Thermal cycle of the process was also studied as to understand the thermal cycle effect on the hardness and microstructure of the overlay. The effect of overlay beads overlapping percentage on the microstructure and hardness was studied as well as the overlapped region undergoes more thermal effect of the process. The process parameters were optimized for improving the overlay hardness as well as bead width and height. Response surface methodology (RSM) using Design Expert software was applied for the design of experiment (DOE) and process parameters optimization in this study. The proposed optimized parameters focusing on maximizing the hardfacing overlay hardness are having hardness values within the targeted range from 610 HV_{60} to 810 HV_{60}. The WC particles content was concluded as not significant in affecting the hardness value of the overlay at macro level. Heat input of the process has direct correlation to the bead height and width of the overlay but indirect correlation to the hardness of the overlay. The temperature reading of the hardfacing process as high as 1351°C was recorded in the thermal cycle investigation and the temperature reading implies that such phases like borides and silicides could have formed in the overlay and dictating the overlay hardness value. Process optimization was done and the optimization focusing on maximizing the hardness value by the software suggested sets of parameters having reliability value close to 1. The suggested sets of parameters have potential to be employed for improving the hardness of the gray cast iron substrate surface.

ABSTRAK

Proses pengerasmukaan menggunakan bahan aloi nikel-tungsten karbida (Ni-WC) telah dilakukan ke atas substrat besi tuang kelabu menerusi kaedah kimpalan arka gas logam (GMAW) *dan kajian mengenai kesan proses tersebut ke atas mikrostruktur serta kekerasan lapisan telah dilakukan. Masalah gerigi sentiasa berlaku pada kepingan keluli yang dihasilkan menerusi proses ricih dalam industri automotif dan masalah ini adalah disebabkan oleh kehausan pada dai yang terdapat pada mesin proses ricih. Masalah ini lebih cenderung berlaku pada dai besi tuang kelabu yang mempunyai nilai kekerasan yang rendah.* Ni-WC *adalah bahan pengerasmukaan yang sangat keras dan mempunyai potensi untuk digunakan sebagai bahan pengerasmukaan ke atas dai besi tuang kelabu. Penggunaan kaedah* GMAW *untuk tujuan proses pengerasmukaan perlu dilakukan dengan penuh perhatian terhadap aspek input haba kerana input haba yang terhasil boleh memberi kesan terhadap mikrostruktur lapisan pengerasmukaan tersebut dan seterusnya memberi kesan terhadap sifat kekerasan lapisan pengerasmukaan tersebut. Kesan parameter-parameter proses terhadap kekerasan dan mikrostruktur lapisan pengerasmukaan dikaji kerana parameter-parameter proses mempunyai kaitan terhadap input haba yang dihasilkan. Kesan parameter-parameter proses terhadap kelabaran dan ketinggian kumai lapisan pengerasmukaan juga dikaji kerana kelabaran dan ketinggian kumai merupakan dua aspek penting pada lapisan pengerasmukaan. Kitaran haba proses juga dikaji untuk memahami kesan kitaran haba terhadap kekerasan dan mikrostruktur lapisan pengerasmukaan. Kesan jumlah peratusan tindihan antara kumai-kumai lapisan pengerasmukaan juga dikaji kerana kawasan tindihan antara kumai-kumai tersebut mengalami kesan tindakan haba yang lebih berbanding kawasan luar tindihan. Parameter-parameter proses telah dioptimakan untuk menambahbaik kekerasan serta kelebaran dan ketinggian kumai lapisan pengerasmukaan. Kaedah gerak balas permukaan menerusi perisian* Design Expert *telah diaplikasikan untuk tujuan rekabentuk eksperimen dan pengoptimaan parameter-parameter proses bagi kajian ini. Set-set parameter optimum untuk tujuan memaksimumkan nilai kekerasan lapisan pengerasmukaan yang dicadangkan mempunyai nilai-nilai kekerasan yang berada dalam julat yang disasarkan iaitu antara 610 HV_{60} hingga 810 HV_{60}. Kandungan zarah-zarah tungsten karbida tidak signifikan dalam mempengaruhi nilai kekerasan lapisan pada tahap makro. Input haba proses mempunyai kaitan secara langsung terhadap ketinggian dan kelebaran kumai lapisan pengerasmukaan dan tidak secara langsung terhadap nilai kekerasan lapisan. Bacaan suhu setinggi 1351°C telah dicatatkan semasa kajian terhadap kitaran haba dan bacaan suhu tersebut menandakan bahawa fasa-fasa seperti borida dan silisida berkemungkinan telah terbentuk dalam lapisan yang dihasikan dan mempengaruhi variasi nilai kekerasan lapisan tersebut. Proses pengoptimaan telah dilakukan pada akhir kajian dan set-set parameter untuk memaksimumkan nilai kekerasan lapisan pengerasmukaan yang dicadangkan oleh perisian* Design Expert *mempunyai nilai kebolehpercayaan menghampiri 1. Set-set parameter yang telah dicadangkan mempunyai untuk diaplikasikan bagi meningkatkan nilai kekerasan permukaan substrat besi tuang kelabu.*

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LIST OF ABBREVIATIONS

3D	-	Three Dimensional
A	-	Ampere
ABS	-	Acrylonitrile Butadiene Styrene
AES	-	Auger Electron Spectroscopy
AISI	-	American Iron and Steel Institute
ANOVA	-	Analysis of Variance
ASTM	-	American Society for Testing and Materials
B	-	Boron
C	-	Carbon
C_2H_2	-	Acetylene
CAT	-	Cyclic Abrasion Test
CCO	-	Chromium Carbide Overlay
CCWJ	-	Canadian Center of Joining and Welding
CIAT	-	Cyclic Impact/Abrasion Test
Cr	-	Chromium
DIN EN	-	German Edition of a European Standard
DOE	-	Design of Experiment
EN	-	European Standard
ESW	-	Electroslag Welding
FCAW	-	Flux Cored Arc Welding
FZ	-	Fusion Zone
GMAW	-	Gas Metal Arc Welding
GTAW	-	Gas Tungsten Arc Welding
HAZ	-	Heat Affected Zone
HI	-	Heat Input
HPDL	-	High-Powered Diode Laser
HRC	-	Rockwell C Hardness
HV	-	Vickers Hardness

HVOF	-	High Velocity Oxygen Fuel
kgf	-	Kilogram-Force
kJ	-	Kilojoule
LBW	-	Laser Beam Welding
LIHRC	-	Laser Induction Hybrid Rapid Cladding
MMC	-	Metal Matrix Composite
Mn	-	Manganese
MPa	-	Megapascal
Ni	-	Nickel
NiCrBSi	-	Nickel-Chromium-Boron-Silicon
Ni-WC	-	Nickel-Tungsten Carbide
PAW	-	Plasma Arc Welding
PMMA	-	Polymethyl Methacrylate
PTAW	-	Plasma Transfer Arc Weld
r	-	Correlation Coefficient
RP	-	Rapid Prototyping
RSM	-	Response Surface Methodology
R-Squared	-	Coefficient of Determination
SEM	-	Scanning Electron Microscopy
Si	-	Silicon
SiC	-	Silicon Carbide
SMAW	-	Shielded Metal Arc Welding
V	-	Voltage
W	-	Tungsten
W_2C	-	Tungsten Hemicarbide
WC	-	Tungsten Carbide

LIST OF SYMBOLS

°C	-	Celcius degree
φ_e	-	Ratio of bead width to height
C%	-	Beads overlapping percentage
d	-	Center distance
h	-	Bead height
I	-	Arc current
o	-	Width of beads overlapping area
S	-	Travel Speed
V	-	Arc voltage
w	-	Bead width

LIST OF PUBLICATIONS

Hussein, N.I.S., Ayof, M.N., Rasidi, M.K.S., and Zuhairi J., 2013. Stainless Steel Cladding on Cast Iron Trim Cutter using Gas Metal Arc as Heat Source. *Proceedings of Malaysian Technical Universities Conference on Engineering & Technology (MUCET 2013)*. 3-4 December. Pahang: Universiti Malaysia Pahang (UMP).

Hussein, N.I.S., Kamarul, S.R., Ayof, M.N., 2013. Preliminary Study of Cladding Process on Gray Cast Iron Substrate. *International Journal of Research in Engineering and Technology*, 2, pp. 5-11.

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CHAPTER 1

INTRODUCTION

1.0 Background Study

Metal deposition process is a process where a filler metal is deposited onto a substrate for the purpose of improving the properties of the substrate. The deposition process is commonly employed in a wide range of industries, either for the maintenance or manufacture of new components (Buchanan et al., 2007). Cladding is a metal deposition process which can be done through welding processes such as gas metal arc welding (GMAW), shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), plasma arc welding (PAW) and electroslag welding (ESW) (Rao et al., 2011). Some researchers identify the process as hardfacing and weld-deposited wear resistant overlays (Badisch and Kirchgaßner, 2008; El Banna et al., 2000; Katsich and Badisch, 2011; Mendez et al., 2014).

At present, there are two common material systems used for the hardfacing process; Ni-WC and CCO (Mendez et al., 2014). In the Ni-WC material system, the NiCrBSi alloy acts as the matrix or the binder for the system whereas the WC are the reinforcement particles possessing high hardness in mechanical property. These WC particles are essential in achieving the wear properties in the overlays. On the other hand, the CCO material system, mainly consisting of iron, chromium, and carbon, does not initially come with the carbide particles. The carbides are nucleated within the melt of the overlays. However, the CCO system is lower in wear resistance than the Ni-WC.

Gray cast iron is the most common type of cast iron. It has moderate strength, excellent damping and machinability, but poor ductility. The tensile strength of gray cast iron is up to 275 MPa (Bushery, 2010). However, it has low hardness values of 260 to 340 HV. The common problem when performing sheet metal shearing process using a trim cutter die made from gray cast iron in the manufacturing of automotive components made from low or medium steel sheet is the formation of burr at the edge of the produced blank (Miyazu, 2012). The formation of the burr is expected to be reduced if the trim cutter die has the hardness value is the range of 610 to 810 HV (Miyazu, 2012). Hardfacing process using GMAW method is seen to be a potential process that can be utilized to increase the surface hardness of gray cast iron trim cutter die as the method is relatively low in cost and flexible in practicality (Lundbäck and Lindgren, 2011; Scott, 2011).

However, applying a hardfacing process using GMAW method upon a gray cast iron is difficult because of the inherent brittleness characteristic of the material (Pouranvari, 2010). Therefore, a suitable filler material is needed for the application of the process on gray cast iron substrate as the substrate is susceptible to cracking and nickel alloy has been proven as the correct choice for the filler (Pouranvari, 2010). The presence of nickel content in the alloy enables Ni-WC tubular wire to be a potential filler material for the GMAW based hardfacing process on gray cast iron substrate.

It is crucial to govern the heat input of the process using Ni-WC filler as it is necessary to prevent the WC particles which are required for the desired wear resistance characteristic, from melting and dissolving in the overlay (Badisch and Kirchgaßner, 2008; Mendez et al., 2014). In order to understand the hardfacing process based on GMAW method, the Ni-WC tubular wire was deposited on gray cast iron substrate in terms of singular and overlapping beads overlay. A better understanding on the microstructural evolution and the yielded hardness of the material would be achieved through the process.

1.1 Problem Statement

The hardness value of gray cast iron is relatively low which is in the range of 260 to 340 HV (Sandvik, 2010). A sheet metal shearing process on low and medium carbon steel sheet metal using gray cast iron trim cutter die will result in burr formation at the edge of the produced blank (Miyazu, 2012). According to Noresam from Miyazu Malaysia Sdn. Bhd. (2012), by increasing the hardness of the trim cutter die to the range from 610 until 810 HV, the burr formation is expected to reduce. Hardfacing or cladding is a deposition process which has a potential to be used to increase the hardness of the trim cutter die.

There are studies have been done on hardfacing process using laser as the heat source and it is proved to be an effective method (Fernández et al., 2005; Huang et al., 2011; Tong et al., 2010). According to Fernández et al. (2005), laser cladding technique can be used to melt a wide range of materials onto a metallic substrate and the coatings have minimal dilution, very low porosity, and a perfect union with the substrate. Tong et al. (2010) state that the laser cladding provides good metallurgical bonds, minimal dilution, and low distortion of the parts. Huang (2011) states that laser cladding provides lower dilution, lower distortion and better processing flexibility if compared to other methods such as GTAW or SMAW. However, laser cladding technique requires relatively high cost machinery and the industry prefer lower cost equipment such as arc heat source machinery. Hardfacing process by means of GMAW offers high deposition rates at a relatively low cost as stated by Lundbäck and Lindgren (2011) and it is suitable to be utilized for the hardfacing process on the gray cast iron die in the industry.

The use of GMAW method for the purpose of hardfacing process in the industry nevertheless needs to be done attentively in the aspect of the heat input because the produced heat input of the process could jeopardize the desired microstructure of the overlay (Mendez et al., 2014). Ni-WC hardfacing wire is a popular hardfacing alloy