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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

CHARACTERIZATION AND PARAMETRIC EVALUATION OF WIRE ELECTRICAL DISCHARGE MACHINING OF COLD WORK TOOL STEELS

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A thesis submitted
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DECLARATION

I declare that this thesis entitled "Characterization and Parametric Evaluation of Wire Electrical Discharge Machining of Cold Work Tool Steels" 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.

Signature : ....

Name : Mohd Aidil Shah Bin Abdul Rahim

Date : 27/11/2019...

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 Doctor of Philosophy.

Signature : ……………………………………………..

Supervisor Name : Ir. Dr. Mohamad Bin Minhat

Date : 25 NOV 2019

DEDICATION

To my beloved parents

Faridah bte Maaroff

&

Abdul Rahim bin Abdul Hamid

To my wife,

Nazatul Azlin binti Abdullah

To my sons and daughters

Humairah binti Mohd Aidil Shah

Huzaifah bin Mohd Aidil Shah

Hurairah bin Mohd Aidil Shah

Hurul Ain binti Mohd Aidil Shah

And to all my peers and siblings

Who have made

The past memorable

The present exciting

And the future promising

ABSTRACT

XW42 is a cold work tool steels which is suitable for mould and die application. It has been proven to have an impair value of hardness and toughness which need to be improved. This research provides finding on M1 and M3 which provide an increase in its bulk hardness from 51.5HRC to 52HRC (M1) and 52.6HRC (M3) and its impact toughness from 6.84J to 5.78J (M1) and 8J (M3). Precipitation of hard carbides such as $Cr_{23}C_6$, Cr_7C_3, CrC and V_2C are the cause for high hardness and segregation of eutectic carbide network cause for high toughness. M2 with lower bulk hardness at 49.8HRC and lower toughness at 5.03J due to low carbon content. Micro-hardness value for XW42, M1, M2 and M3 were 614HV, 613.7HV, 613.4HV and 617HV. M3 keen to have the smallest grain size at 63.4μm followed with M1 (64μm), XW42 (65.3μm) and M2 (66.7μm). The combined effects of the machine factors on three machine responses were investigated by employing two levels of full factorial design (FFD) and analysis of variance (ANOVA). The results showed that material removal rate (MRR) was strongly influenced by the interaction of T_{on}/V and V/WT while surface roughness (SR) was dominantly controlled by T_{on}, and white layer thickness (WLT) was strongly controlled by V. Machinability through wire electrical discharge machining (WEDM) revealed that M3 could produce the lowest WLT at 144.32μm at T_{on}: 2μs, V: 10V, WT: 120N meanwhile the highest MRR resulted with the lowest at SR 1.92μm are produced at T_{on}: 2μs, V: 6V, WT: 120N. An average error values of 8.67%, 0.7% and 8.2% between measured and predicted values of MRR, SR and WLT provides guidance for high skill machinery in completing quality end product. M3, with this characterization and machinability, it is keen to undergo the process of cutting, punching and shearing within the thickness up to 12mm.

ABSTRAK

XW42 adalah bahan terbaik dalam pembuatan pelbagai acuan dan di dalam industri. Kajian ini memberikan keputusan terhadap M1 dan M3 dengan kekerasan pukal 52HRC dan 52.6HRC dengan nilai keutuhan 5.78J (M1) dan 8J (M3). Kemendakan karbida keras seperti $Cr_{23}C_6$, Cr_7C_3, CrC dan V_2C memberikan impak terhadap nilai kekerasan dan penghapusan rangkaian karbida meningkatkan keutuhan. M2 dengan nilai kekerasan pukal dan keutuhan yang rendah pada 49.8HRC dan 5J berpunca daripada peratusan kandungan karbon yang rendah. M3 terdiri daripada saiz bijirin yang paling kecil pada 63.4µm diikuti M1 (64µm), XW42 (65.3µm) dan M2 (66.7µm). Kesan gabungan 3 faktor dan kesan mesin telah dikaji dengan menggunakan dua tahap reka bentuk faktorial penuh (FFD) dan analisis varians (ANOVA). Hasil kajian menunjukkan bahawa kadar kikisan bahan (MRR) telah dipengaruhi oleh interaksi T_{on}/V dan V/WT manakala kekasaran permukaan (SR) dikawal dominan oleh T_{on}, dan ketebalan lapisan putih (WLT) sangat dikuasai oleh V. Pemesinan melalui mesin pelepasan wayar elektrik (WEDM) mendedahkan bahawa M3 boleh menghasilkan WLT terendah pada 144.32µm di T_{on}: 2µs, V: 10V, WT: 120N manakala MRR tertinggi sebanyak 0.00811kg/s dengan SR 1.92µm yang terendah pada T_{on}: 2µs, V: 6V, WT: 120N. Dengan purata ralat pada 8.67%, 0.7% dan 8.2% bagi MRR, SR dan WLT, menyediakan petunjuk kepada pekerja kemahiran tinggi untuk menghasilkan produk yang berkualiti. M3, aloi dengan karakteristik dan kebolehkerjaan ini, mampu mengharungi proses pemotongan, alat penekan dan ricihan dengan bahan kerja yang berketebalan sehingga 12mm.

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LIST OF SYMBOLS AND ABBREVIATIONS

Ø	-	Diameter
γ	-	Austenite
α	-	Ferrite
A1	-	Eutectoid Temperature
ANOVA	-	Analysis of Variance
C	-	Carbon
Ce	-	Cerium
Co	-	Cobalt
Cr	-	Chromium
CS	-	Cutting Speed
Cu	-	Copper
DA	-	Double Austenitisation
DT	-	Double Tempered
FFD	-	Full Factorial Design
La	-	Lanthanum
Mn	-	Manganese
Mo	-	Molybdenum
MRR	-	Material Removal Rate
Nb	-	Niobium

Ni - Nickel

P - Phosphorus

S - Sulphur

Si - Silicon

SR - Surface Roughness

T_{on} - Pulse on time

Ti - Titanium

V - Vanadium

W - Tungsten

Wt% - Weight percentage

WEDM - Wire Electrical Discharge Machining

WLT - White Layer Thickness

WT - Wire Tension

LIST OF PUBLICATIONS

1. Abdul Rahim, M. A. S., Minhat, M., Hussein, N. I. S., and Salleh, M. S., 2018. A comprehensive review on cold work of AISI D2 tool steel. *Metallurgical Research and Technology*, 115(1), pp. 1-12.
2. Abdul Rahim, M. A. S., Minhat, M., Hussein, N. I. S., and Rahman, M. N., 2018. Performance evaluation and microstructural characteristics of improved tool steel alloy XW42 by WEDM. *Journal of Physics: Conference Series*, pp. 1-6.
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4. Abdul Rahim, M. A. S., Minhat, M., Hussein, N. I. S., Salleh, M. S, Sabdin, S., and Mohd Zain, A., 2018 'An experimental investigation on the effect of parameters on material removal rate and white layer thickness during machining of hard steel'. *Journal of Advanced Manufacturing Technology* – Under Review
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CHAPTER 1

INTRODUCTION

1.1 Background

The demands for cold work tool steel (CWTS) alloy materials having high hardness and toughness, wear resistance, corrosion resistance, and impact resistance are increasing through the development of mechanical and manufacturing industries. In achieving these advantages, Nayak et al., (2016) pointed out that vanadium, molybdenum, tungsten and other elements including some rare earth elements such as cerium and lanthanum with certain percentages are added to the base materials which forms alloyed tool steel to enhance these mechanical properties. This materials which upon heat treatment exhibit excellent strength, hardness, toughness and wear resistance relative to other steel types.

Unfortunately, machining through conventional machining of cold tool steel alloy will include several critical issues, such as poor surface quality, low dimensional accuracy, high tool wear and poor machinability. These issues are commonly observed because of poor toughness, hardness, and thick white and recast layer after machining will lead to micro-cracks and cracks, brittle and poor Surface roughness.

XW42 is a high carbon high chromium (HCHCr) steels employed in the application of drawing and forming, cold drawing punches, blanking/stamping dies and extrusion dies. Die steels are subjected to continued compressive tensile stresses, shear stresses and require high strength and toughness with good Surface roughness. Bombac et al., (2013) claimed that mechanical properties of these alloys are mainly determined by the alloying elements, austenite grain size, sub grain size, martensitic lath width, dislocation density and precipitates.

It has been reported that XW42/SKD11/AISI D2 usually have the properties of high hardness with poor toughness. Hamidzadeh et al., (2012) revealed this may be due to slow cooling of the conventional static ingot casting which allows the formation of coarse and net-like eutectic carbides dendrites within the dendrites of prior austenite (see Figure 1.1). These carbides form a network along the grain boundaries which results in an easy forming of micro cracks and cracks causing low toughness to be achieved.

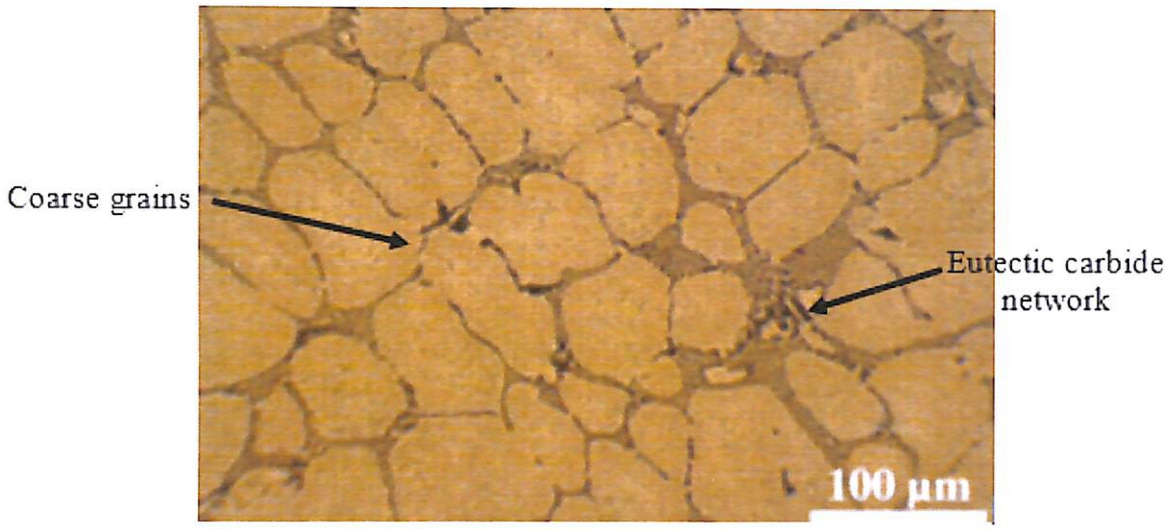

Figure 1.1: An optical micrograph showing the distribution of eutectic carbides of AISI D2 steel alloy in annealed condition (Hamidzadeh, 2013)

A considerable amount of literature has been published on cold work tool steel alloy which forms a hard to machine material due to the appearance of different compositions of alloy carbides in the matrixes and the heat treatment process. Likewise, Torkamani et al., (2014) held the view that these elements improve wear resistance and hardness of the