Faculty of Manufacturing Engineering

MACHINING PERFORMANCE OF 22MnB5 BORON STEEL CUTTING TOOL WITH AL 6061 ALUMINIUM ALLOY

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A thesis submitted
in fulfilment of the requirements for the degree of Master of Science
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2021

DECLARATION

I declare that this thesis entitled "Machining Performance of 22MnB5 Boron Steel Cutting Tool with Al 6061 Aluminium Alloy" 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 Fairuz Bin Mohd Rashid

Date : 30 October 2021

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 : Associate Prof. Ir. Dr. Mohd Hadzley bin Abu Bakar

Date : 30 October 2021

DEDICATION

To my beloved father, mother, my family, my supervisor and my supportive friends that accompanying me along the difficult pathway in my university life.

ABSTRACT

Machining is a process to manufacture a product by removing portion of material by using cutting tool. In machining aluminium alloy, the usage of high speed steel (HSS) cutting tool have dominant due to versatility and superior hardness. However, HSS cutting tool is very prone to wear in high-speed machining due to the low hot hardness. Such condition affected productivity as worn cutting tool detrimental to the machined surface and the production need to stop to replace the cutting tool. In the recent advancement of machine tool technology, a new type of steel already applied for automotive structure. This steel, named as 22MnB5 Boron Steel, produced by the hot stamping process where the sheet metals were formed and heat treated inside metal stamping dies. 22MnB5 Boron Steel categorized as ultra-high strength steel with 1500 MPa tensile strength and 80 HRC hardness. Such properties resembled almost similar to HSS which make them potential to be applied as cutting tool. The purpose of this study is to investigate the capability of 22MnB5 Boron Steel as a cutting tool in machining aluminium alloy. Initial part of study involved with analysis on the physical and mechanical properties of 22MnB5 in terms of hardness, density, tensile strength, surface appearance and coefficient of friction. The second part covers machining trials of 22MnB5 Boron steel on Al 6061 Aluminum Alloy using various condition and parameters. Lastly the third parts cover assessment of failure modes and wear mechanism of 22MnB5. The results show that combination of high hardness of 70HRC, density of 7.841 g/cm^3 and tensile strength of 1500 MPa facilitate strong edge of 22MnB5 to machine Al 6061 smoothly. 22MnB5 capable to machine Al 6061 Aluminum Alloy in wet condition up to 861 s at 200 m/min, 0.1 mm/rev and 0.5 mm cutting speed, feed rate and depth of cut respectively. The wear mechanism showed up as fragmented debris and built up layer dominated the flank and crater surfaces with abrasive and adhesive effects. This study built better understanding of 22MnB5 characterization in operation that involved with friction, tribology and machining. Finding from this study could also benefit the industries in terms of selection of cutting tools that capable to machine product with sustainable manufacturing approach.

PRESTASI PEMESINAN ALAT PEMOTONG 22MnB5 KELULI BORON DENGAN ALOI ALUMINIUM Al 6061

ABSTRAK

Pemesinan adalah satu proses pembuatan produk dengan membuang sebahagian bahan menggunakan perkakas pemotong. Dalam pemesinan Aloi Aluminum, penggunaan perkakas pemotong keluli berkelajuan Tinggi (HSS) adalah dominan kerana ianya serba boleh dan berkekerasan tinggi. Walaubagaimanapun, perkakas pemotong HSS mudah untuk haus pada halaju pemesinan tinggi kerana kekerasan panas yang rendah. Keadaan ini memberi kesan kepada produktiviti kerana perkakas pemotong yang haus memudaratkan permukaan termesin and pengeluaran perlu dihentikan bagi mengganti perkakas pemotong. Dalam teknologi perkakas mesin termaju, satu keluli baru telahpun digunakan dalam industri automotif. Keluli yang dinamakan 22MnB5 Keluli Boron ini, dihasilkan dari proses pencetakan panas di mana kepingan logam dibentuk dan dirawat haba dalam dai pencetak logam. 22MnB5 Keluli Boron dikategorikan sebagai keluli kekuatan ultra tinggi dengan 1500 MPa kekuatan tegangan dengan kekerasan 80 HRC. Sifat-sifat ini hampir menyamai kepada HSS yang mana berpotensi untuk digunakan sebagai perkakas pemotong. Tujuan kajian ini adalah untuk menyiasat kemampuan 22MnB5 Keluli Boron sebagai perkakas pemotong untuk pemesinan Aloi Aluminum Al 6061. Bahagian awal dalam kajian melibatkan analisa sifat-sifat fizikal dan mekanikal 22MnB5 dari segi kekerasan, ketumpatan, kekuatan tegangan, keadaan permukaan dan pekali geseran. Bahagain seterusnya melibatkan ujian pemesinan 22MnB5 terhadap Aloi Aluminum Al 6061 pada pelbagai keadaan dan parameter. Bahagian terakhir melibatkan penilaian mod kegagalan dan mekanisma haus untuk 22MnB5. Keputusan menunjukkan kombinasi kekerasan tinggi 70 HRC, ketumpatan 7.841 g/cm^3 dan kekuatan tegangan 1500 MPa membolehkan 22MnB5 memesin Al 6061 dengan lancar. 22MnB5 mampu memesin Al 6061 Aloi Aluminum dalam keadaan basah sehingga 861 s pada halaju pemesinan, kadar suapan dan kedalaman pemotongan masing-masing 200 m/min, 0.1 mm/rev dan 0.5 mm. Mekansima haus menunjukkan serpihan terpecah dan lapisan terbina mendominasi permukaan haus rusuk dan kawah dengan kesan abrasif dan adesif. Kajian ini membina kefahaman lanjut mengenai sifat-sifat 22MnB5 dalam aplikasi melibatkan geseran, tribologi dan pemesinan. Dapatan dari kajian ini juga memberi penambaikan kepada industri dari segi pilihan perkakas pemotong yang mampu memesin produk dengan pendekatan kelestarian pembuatan.

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LIST OF ABBREVIATIONS

AISI	-	American iron and steel institute
Al	-	Aluminium
Al_2O_3	-	Aluminium oxide/ alumina
ASTM	-	American society for testing and materials
BUE	-	Built-up edge
CBN	-	Cubic boron nitride
CeO_2	-	Cerium oxide
CIP	-	Cold isostatic press
CNC	-	Computer numerical control
CrN	-	Chromium nitride
EN	-	Euro norm
F	-	Feed rate
Ff	-	Load at fracture
HIP	-	Hot isostatic press
HSS	-	High speed steel
ISO	-	International standard organization
L	-	Distance
Mg	-	Magnesium
MgO	-	Magnesium oxide/ magnesia
O	-	Oxygen
PM	-	Powder metallurgy

R	-	Radius
S_3N_4	-	Silicon nitride
SEM	-	Scanning electron microscope
SiC	-	Silicon carbide
TiAlN	-	Titanium aluminium nitride
$TiBr_2$	-	Titanium bromide
TiC	-	Titanium carbide
TiCN	-	Titanium carbon nitride
TiN	-	Titanium nitride
Vc	-	Cutting speed
W	-	Weight
Y_2O_3	-	Yttrium oxide
Zr	-	Zirconium
ZrN	-	Zirconium nitride

LIST OF SYMBOLS

m/min	-	Meter per minute
%	-	Percent
°C	-	Degree Celsius
mm	-	Millimeter
µm	-	Micrometer
K	-	Kelvin
kg/m^3	-	Kilogram per cubic meter
mm/rev	-	Millimeter per revolution
N	-	Newton
kW	-	Kilowatt
rpm	-	Revolution per minute
Nm	-	Newton meter
L/min	-	Liter per minute
HRC	-	Rockwell C hardness
HV	-	Vickers hardness
MPa	-	Megapascal
W/ m/K	-	Watts per meter per kelvin

J/ g.K	-	Joule per gram per kelvin
GPa	-	Gigapascal
Psi	-	Pound per square inch

LIST OF PUBLICATIONS

Journal

1. Rashid, M. F. M., Osman, M. H., Bakar, M. H. A., Azhar, A. A., Yusoff, W. A. W., & Thongkaew, K. (2020). Tool wear model and wear mechanisms when machining TiAlN ball end mill with high thermal conductivity steel (HTCS 150). *Jurnal Tribologi*, *24*, pp. 15–26.
2. Mohd Hadzley Abu Bakar, Mohd Fairuz Rashid, Norfauzi Tamin, Umar Al Amani, Safarudin Gazali Herawan 2020. Application of 22MnB5 Boron Steels as Cutting Tools in Machining Aluminium Alloy. Proceedings of Mechanical Engineering Research Day 2020, pp. 1-2.

CHAPTER 1

INTRODUCTION

1.1 Research background

Hot stamping is a process of creating metal parts by applying high pressure to a part using special made dies and forming the metal into a desired shape. During hot stamping process, a blank part is heated up before stamped and cooled or quenched in the die enclosure (Chen et al., 2020). The process involved with several machinery such as furnace and hot stamping machine with cooling system, assisted by robots and conveyor systems. Hot stamping reportedly capable to increase the strength of steel up to 4 folds, reduces the structural weight by using thinner sheet metal and eliminates spring back effect, as compared to conventional metal stamping. Figure 1 shows the illustration of hot stamping process. The use of hot stamped components improved structural integrity and crash performance of the car, which enable cars to achieve 5 stars in safety assessment by Asean New Car Assessment Program (ASEAN NCAP) (Bulletin & No, 2019).

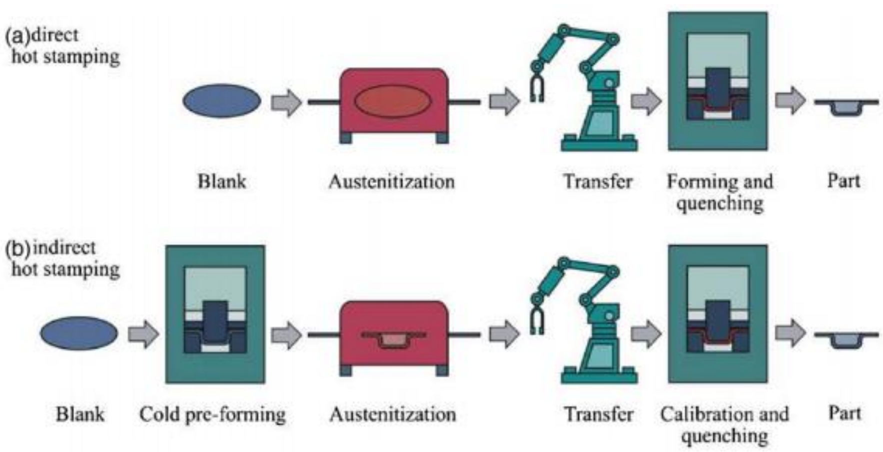

Figure 1.1: Illustration of hot stamping process (Karbasian and Tekkaya, 2010)

One of the most widely material used as hot stamping parts is Boron alloy 22MnB5. 22MnB5 normally prepared in sheet metal form and applied in automobile structural and safety components. The very high mechanical strength and thinner part makes it possible to achieve weight savings of 30% to 50% as compared to conventional cold forming grades, such as High Strength Low Alloy steel (HSLA 550), steel that normally used in normal vehicle.

22MnB5 alloy has carbon content around 0.23% to retain weldability and formability. Other alloying elements include up to 1.2% Manganese and Boron which have a significant influence to increase the hardenability (Abdulhay et al., 2011). The efficiency of 22MnB5 after being processed with hot stamping process strongly depended on microstructure of hot stamping part and cooling capability of hot stamping die. The microstructure of hot stamping part affected the properties of final product, which depended on chemical compositions and microstructure sensitivity during quenching process. The cooling capability of hot stamping die depended on the surface roughness, thermal conductivity and parameters during part pressing. The design of cooling channel inside the die controls the cooling rate which in the end controls the microstructure of final product (Zhu et al., 2020).

In the past, significant material and application research pertaining to 22MnB5 has been carried out but the focus has mainly been on the vehicle fabrication and bearing parts. An investigation on fracture toughness of 22MnB5 steel sheets was performed by the ability to form different microstructures with different mechanical properties has allowed 22MNB5 in versatile applications for weight reduction and addressing crash safety requirements. Lara et al., 2013 found that when applying as vehicle chassis, fatigue performance of 22MnB5 depended on the cut edge surface quality. The cracks that generated from cutting process by stamping dies might have induced burr formation and rollover zone that could degraded fatigue resistance of the chassis joining. Nikravesh et al., 2015 studied the microstructure evolution of bearing 22MnB5 and found that plastic deformation at elevated temperature contributed to the refinement of microstructure and altering their mechanical properties. Such transformation also affected the hardness of the finished parts.

Yao et al., 2018 looked at the processing of 22MnB5 in rolling condition and concluded that initial condition is important to pre-determine microstructure evolution. Recently, Yao et al., 2020 indicated that 22MnB5 can effectively been applied as car structure, especially when assembled with other high strength steel. The welding trial between these steels highlighted the importance of microstructure control to form efficient welding fusion. The results showed that the heat treatment process was an important factor in determining the mechanical in the mixed heating and cooling regime.

From the literature studies, it can be summarised that 22MnB5 Boron Steel is applicable in automotive industry specially to facilitate the demand of high strength and lightweight structured. In advance, the high hardness and fracture toughness have allowed 22MnB5 to be applied in aggressive operation such as hard friction, fatigue and thermal stresses. These advantages can be exploited in others application where strong and hard structure of 22MnB5 could be beneficial to shear another softer material. In this research, we intend to innovate 22MnB5 Boron Steel to be applied as a cutting tool since their refractory conditions could be potential in aggressive material removal operation.