STUDY OF MACHINABILITY ON DRILLING
AUSTENITE STAINLESS STEEL 316 L1
BY SOLID CABIDE TOOL

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ABSTRACT

Austenite stainless steel is one of the most important engineering materials with wide variety of applications. Superior resistances to corrosion and compatibility in high temperature and high vacuum have particularly made it an attractive choice. However, the machinability of austenitic stainless steel is not very promising owing to lower thermal conductivity, higher degree of ductility and work harden ability. Grade 316 L1 is the standard molybdenum- bearing grade. Molybdenum gives 316 better corrosion resistance properties than crevice corrosion in chloride environment. It has excellent forming and welding characteristics. Over the years, cemented carbide (WC-Co) has overcome many drawbacks of high speed steel (HSS) as cutting tool materials and become one of the most versatile cutting tool materials during machining both ferrous and non ferrous alloys. There are mainly three grades of cemented carbide cutting tool example K, P and M grades. Steel being very ductile in nature produces long, continuous chip during machining. Moreover, iron in steel has greater affinity towards carbon of WC of the tool. P grade, is more diffusion resistant grade due to presence of more stable carbide like TiC, TaC and NbC. Therefore, P grade is also known as mixed carbide grade and more suitable for machining steel. Since P30 grade of cemented carbide would provide excellent balance of hardness, wear resistance and toughness, the same grade has been chosen for machining of stainless steel. In the first phase of work, tool life test would be carried out using three different cutting velocities (110, 130 and 150 m/min) with constant feed of 0.2mm/rev and constant depth of cut of 1mm for different duration of machining. Tool life study would be based on average flank wear, VB= 0.3 mm criterion. Flank wear would be measured using a zoom optical microscope. Therefore, effect of cutting speed on tool life of uncoated P30 grade carbide insert would be studied during machining of 316 grade of austenitic stainless steel.

ABSTRAK

Austenite stainless steel adalah bahan kejuruteraan yang paling penting kerana ianya mempunyai pelbagai kegunaan dan faedah. Daya ketahanan terhadap karat dan kemampatannya kepada suhu yang tinggi dan berkeadaan vakum, menjadi sebagai salah satu pilihan untuk kegunaan terpakai. Walau bagaimanapun, keupayaan memesin *Austenite stainless steel* adalah tidak dapat ditentukan terhadap konduktor haba yang lemah, tinggi kerapuhan, dan keupayaan kerja keras. Molybdenum 316 adalah tahan karat yang lebih baik berbanding karat ceruk di dalam persekitaran klorida. Ia adalah pembentukan yang terbaik dan ciri- ciri kimpalan. Bertahun- tahun *cemented carbide (WC-Co)*menangani kekurangan pada *high speed steel (HSS)*sebagai mata pemotong dan menjadi bahan yang paling versatile antara besi dan bukan besi. Terdapat tiga gred *cemented carbide* pemotong iaitu gred K,P dan M. Keluli adalah sangat mulur yang menghasilkan cip yang panjang dan berterusan semasa memesin. Lebih-lebih lagi, besi keluli mempunyai kaitan yang lebih besar ke arah karbon terhadap pemotong. P gred, gred tahan resapan yang lebih kerana kehadiran karbida yang lebih stabil seperti TiC, TAC dan NbC. P gred juga dikenali sebagai gred karbida campuran dan lebih sesuai untuk keluli pemesinan. Sejak P30 gred karbida simen akan menyediakan kira-kira cemerlang kekerasan, rintangan haus dan keliatan, gred yang sama telah dipilih untuk pemesinan daripada keluli tahan karat. Dalam fasa pertama kerja, alat ujian kehidupan akan dijalankan menggunakan tiga halaju pemotongan yang berbeza (110, 130 dan 150 m / min) dengan suapan malar 0.2mm/rev dan kedalaman tetap pemotongan 1mm bagi tempoh yang berbeza pemesinan. Alat kajian hayat akan berdasarkan haus rusuk purata, VB = 0.3 mm kriteria. Haus rusuk akan diukur dengan menggunakan mikroskop zoom optikal. Oleh itu, kesan kelajuan pemotongan mengenai kehidupan alat tidak bersalut P30 gred karbida masukkan akan dikaji semasa pemesinan 316 gred keluli austenit tahan karat.

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INTRODUCTION

1.1 BACKGROUND OF PROJECT

This project has been purposed to study on the tool life of drilling tool of uncoated solid carbide tool. Drilling process will be done on the drilling of stainless steel workpiece. This project is important because it will be as a guideline for students to run drilling process of the stainless steel workpiece using solid carbide tool. At the end of this project, it was expected to come out with the result of tool life of cutting tool and also optimum cutting condition for drilling process. Also, this project helps to reduce tool breakage as well as reduce cost in replace the broken tool with new one. As information, the tool is requiring high cost to buy. Therefore, this project will provide useful information for users especially in drilling process to keep the tool in a good condition.

1.2 PROBLEM STATEMENT

1) How the Minimum Quantity Lubricant (MQL) technique can affect the tool life under very high temperatures during the machining of austenite stainless steel 316LI cutting speed, feed rate and point of angle.

2) The prediction of tool life whether it is longer to use or become shorter by using MQL lubricant will be studied in this project

1. 3 OBJECTIVES OF THE RESEARCH:

To investigate performance and optimum cutting condition of drilling tool. Avoid tool from breakage during machining. Tool is costly, therefore, by setting up the optimum cutting condition, this allow to prevent tool breakage. As well as study chip characteristics.

To setup an experiment on tool life. Apply knowledge on using equipment High Speed Milling Machine and also learn to collect data using Optical Microscope.

To study effect on cutting speed, feed rate and point of angle on tool life. Estimate prolong of tool life, tool wear will be observe under Optical Microscope and analyze from that. Tool wear in friction drilling is a concern because it affects the characteristics and tolerances that are achievable. Therefore, experiment must be done to get optimum value.

1.4 OVERVIEW OF THE PROJECT

1.4.1 Stainless steel

Stainless steel, are also known as corrosion- resistant steel, because it is an iron-based steel alloy, which contain minimum 11% chromium. Chromium present in it prevents it from getting corroded. When ordinary carbon steel is exposed to rain water, it corrodes easily due to formation of a brown iron oxide on the surface, which is commonly called as rust. But when more than 1% chromium added to ordinary steel, the oxide on the surface is transformed. Stainless steel generally has high ductility, weld ability, and cryogenic toughness properties.

Stainless steel differs from carbon steel by the amount of chromium present. When exposed to air and moisture unprotected carbon steel rusts easily. This iron oxide film (the rust) is active and accelerates corrosion by forming more iron oxide.

Two important physical properties are thermal conductivity and thermal expansion rate. Type 304 is the common austenitic stainless steels, which have lower thermal conductivity than carbon steels. Their rate of thermal expansion is also greater than ordinary steel, so care must be taken during welding to ensure that the recommended jigging and tacking procedures and welding sequences are followed.

For most corrosion resistance applications, strength is not a key issue. There are exceptions, such as pressure vessels. A characteristic of the austenitic stainless steel is that their strength increases rapidly when they are formed at ambient temperatures, such as in rolling or wire drawing operations.

1.4.2 Machinability of Stainless steel

Machinability is the term used to denote the machining performance of a material by a cutting tool. The ease with which a given material may be worked with a cutting tool is machinability. Machinability depends on:

a) Chemical composition of job material

b) Structure

c) Mechanical properties

d) Physical properties

e) Cutting conditions

The criteria for judging machinability may be:

a) Tool life

b) Cutting force

c) Surface finish

d) Chip characteristic (Chip colour, chip types, chip thickness, chip reduction coefficient)

e) Cutting temperature

When compared with carbon steels due to their difference in properties, slightly difference technique are required when machining stainless steels. The carbon content of steel greatly affects its machinability. High- carbon steels are very difficult to machine because they are strong and they contain carbides which abrade the cutting tool. Low-carbon steels are “gummy” and stick to the cutting tool, resulting in a built up edge that shortens tool life. Therefore, steel has the best machiniability with medium amounts of carbon, about 0.20%. Chromium, molybdenum and other alloying metals are often added to steel improve its strength. However, most of these metals also decrease machinability.

Stainless steel has poor machinability compared to regular carbon steel because they are tougher, gummier and tend to work harden very rapidly. We can decrease its gumminess and make it easier to cut by slightly hardening the steel.

One of the major advantages of the stainless steel is their ability to be fabricated by all the standard fabrication techniques. The common austenitic grades can be folded, deep drawn, bent, cold and hot forged, spun and roll formed. As the material is of high strength and very high work hardening rate all of these operations require more force than for carbon steels, so a heavier machine may be needed. Austenitic stainless steel also have very high ductility, hence capable of being very heavily cold formed, although they have high strength and high work hardening rate, into items such as deep drawn laundry trough, few other metals are capable of achieving this degree of deformation without splitting.

1.4.3 Different type of stainless steel

Stainless Steels are usually classified into four categories depending on their primary constituent of the matrix:

i. Martensitic stainless steels

It is a high carbon containing steel, having a higher carbon level (nearly 1%) and 18% chromium. Martensitic stainless steel contains chromium (18%), molybdenum (0.21%), nickel (less than 2%), and carbon (about 0.1–1%) giving it more hardness but making the material a bit more brittle. Presence of nickel and molybdenum increases its strength. Martensitic stainless steel can be easily hardened by subjecting it to heat, and it is also highly resistant to abrasion, though it displays less resistance to corrosion compared to other alloys of stainless steel. It has poor weldability and is magnetic. It displays magnetic properties and is used in the manufacture of surgical instruments, valves, knife blades, etc. Increasing hardness typically reduces tool life and machinability. Increasing the carbon content the proportion of abrasive chromium carbides in the matrix increases and reduces tool life and machinability.

ii. Ferritic stainless steels

These are plain chromium stainless steels with varying chromium content between 11% and 18%, but with low carbon content. Ferritic alloys are generally more machinable than other alloys. Their machinability generally decreases with increasing chromium content. They have a moderate to good corrosion resistance, are not harden able by heat treatment and always used in the unhealed conditions. They are magnetic. The formability is not as good as the austenitic. These are commonly used in computer floppy disk hubs , automotive trim , automotive exhausts , material handling equipment and in hot water tanks.

iii. Austenitic stainless steels

Most commonly used austenitic stainless steel contains 18% chromium and 8% nickel. They have an excellent corrosion resistance, weldability, formability fabricability, ductility, clean ability and hygiene characteristics. Along with good high and excellent low temperature properties, these are non magnetic (if annealed) and are hardenable by cold work only.

iv. Duplex stainless steels

These are stainless steels contining relatively high chromium (between 18 and 28%) and moderate amounts of nickel (between 4.5 and 8%). The nickel content is insufficient to generate a fully austenitic structure and the resulting combination of ferritic and austenitic structures is called duplex. Most duplex steels contain molybdenum in a range of 2.5 - 4%. These also have a high resistance to stress corrosion, cracking and chloride ion attacks. They have a higher tensile and yield strength than austenitic of ferritic steels as well as good weldability and formability. They are commonly used in marine applications, desalination plants, heat exchangers and petrochemical plants.

1.4.4 Composition of Different Type of Stainless steel

i. Martensitic stainless steels

Type 410: A 13% chrome, 0.15% carbon alloy possessing good ductility and corrosion resistance. It can be easily forged and machined.

Type 416: similar to 410 but has added sulphur giving improved machinability.

Type 431: a 17% chrome, 21/2% nickel 0.15% max carbon stainless alloy. Has superior corrosion resistance to type 410 and 416 due to nickel. Usually supplied in bar form.

ii. Ferritic stainless steels

Type 430 : a 17% chrome, low alloy ferritic steel. It has good corrosion resistance properties up to about 8000C. Used in strip and sheet form due to its poor machinability.

iii. Austenitic stainless steels

Type 304 : Excellent corrosion resistance in unpolluted and fresh water environment. Contain 18% chrome and 8% nickel.

Type 321 : a variation of type 304 with Ti added in proportion to the carbon content.

Type 347 : uses Niobium instead of Ti

Type 316 : addition of 2-3% molybdenum gives increased corrosion resistance in off shore environments

Type 317 : similar to 316 but the 3-4% molybdenum gives increased pitting resistance when immersed in cold sea water.

iv. Duplex stainless steels

UNS S31803 : composition is 0.03% max. Carbon, 122% Cr, 5.5% Ni, 3% Mo and 0.15% N

UNS S32304 : Typical composition is 0.03% max. Carbon, 23% Cr, 4% Ni and 0.1% N

UNS S32750 : Composition is 0.03% max. Carbon, 25% Cr, 7% Ni, 4% Mo and 0.28% N

1.4.5 Advantages and Application of Austenitic Stainless steel

Austenitic steels have austenite as their primary phase (face centered cubic crystal). These are alloys containing chromium and nickel (sometimes manganese and nitrogen. Austenitic steels are not hardenable by heat treatment. The most familiar stainless steel is Type 304, which is sometimes called T304 or simply 304. Type 304 surgical stainless steel is austenitic steel containing 18-20% chromium and 8-10% nickel. Compared to typical carbon steel, Austenitic stainless steel has high ductility, low yield stress and relatively high ultimate tensile strength. Carbon steel on cooling transforms from Austenite to a mixture of ferrite and cementite. In austenitic stainless steel, the presence of high chrome and nickel content suppress this transformation by keeping the material fully austenite on cooling. Heat treatment and the thermal cycle caused by welding, have no influence on mechanical properties. Strength and hardness can be increased by cold working, which will also reduce ductility. Austenitic steel has good corrosion resistance and excellent high-temperature tensile and creep strength, but still severe corrosion can occur in certain environments.

Applications; it is used for chemical processing equipment, for food, dairy, and beverage industries, for heat exchangers, and for the milder chemicals. Used mostly in the pulp and paper industry. Often used in stacks which contain scrubbers. Sometime used in boat fitting. Woven or welded screens are used for mining, quarrying and water filtration. Sometimes with thread fasteners and springs are also used.

1.4.6 Challenges in Machining Stainless steel

Austenitic Stainless Steel is distinguished by their suitable applicative nature due to their good combination of high chemical properties. These properties are dependent and influenced by quantity and nature of their alloying elements. They are also dependent on the heat treatment used. The major challenges while machining are expressed in high adhesion affinity up to high cutting speed ranges, high thermal loads as well as in a hardening of the material. Further the high toughness leads to an unpropitious chip breakage and increased burr formation. In turning stainless steel, burr formation is of great importance because it influences not only the quality and handling of work piece but also the tool wear.

1.4.7 Grades of stainless steel

Stainless steel grades are iron alloys that contain more than 10.5% of chromium. To amplify its properties other alloys are added to the stainless steel. The grading is based on the metallurgical structure and nature of stainless steel.

Grade 304 is the standard "18/8" stainless; it is the most versatile and most widely used stainless steel, available in a various range of products, forms and finishes. It has excellent forming and welding characteristics.

Grade 316 is the standard molybdenum bearing grade. Molybdenum gives 316 better overall corrosion resistant properties than grade 304. It has excellent forming and welding characteristics. It is readily brake or roll formed into a variety of parts.

Grade 316L, the low carbon version of 316 and is immune from sensitization (grain bounding carbide precipitation). Thus, extensively used in heavy gauge welded component (over about 6mm).

Grade 316H, with its higher carbon content has application at elevated temperature.

Possible alternative grades to 316 stainless steel :

316Ti: Better resistance to temperature of around 600-9000C is needed.

316N: Higher strength than standard 316.

317Lit: Have higher resistance to chlorides than 316L, but with similar resistance to stress, corrosion cracking.

904L: Much higher resistance to chlorides at elevated temperatures, with good formability

220S: Much higher resistance to chlorides at elevated temperatures and higher strength than 316.

1.4.8 Engineering applications of different grades of stainless

Type 301 : Trains, aircraft, belt conveyors, vehicles, bolt, springs

Type 304 : Sink, interior piping, hot water machine, bathtub, boiler, automobiles parts

Type 304L: Machinery & tools used in the chemical, coal & petroleum industry that require

high inter granular corrosion resistance, building material, heat resistance parts and parts that are difficult to treat after fabrication

Type 316 : Material for use in sea-water, equipment for manufacturing dye,paper, acetic acid, fertilizer and chemicals, in the photo industry, food industry, the facilities constructed in the coastal area, bolts

Type 316L : Especially welded products, made with 316 steel that require superior intra granular corrosion resistance

Type 321 : airplane exhaust pipe, boiler cover, bellow & hoses

Type 409L : exhaust pipe, heat exchanger, container, etc.

Type 430 : heat resistance tools, burner, household electric appliance parts, sink cover,

building material, bolts, nuts

1.4.9 Difference Between 304 and 316 of Stainless steel

Type 304 is the most common austenitic grades, containing normally, 20% chromium and 10 % nickel, combined with a maximum of 0.08 % carbon. While type 316 contains 16% to 18% chromium and 11% to 14% nickel. 316 has molybdenum added to the nickel and chrome of the 304. Carbon contain is 0.03 % . The main difference is that 316 contains 2% - 3% molybdenum and 304 has no molybdenum. The “moly” is added to improve the corrosion resistance to chlorides.

Type 304 is used for chemical possessing equipment, for food, for dairy, for heat exchangers, and for the milder chemicals. While Type 316 is used in chemical processing, in the pulp and paper industry, for food and beverage processing and dispensing. In the marine environment, where strength and wear resistance are needed, and type 304 being slightly higher strength and wear resistance than type 316 it is used for nuts, bolts and screws.

Type 316 stainless steel has molybdenum, which gives it more corrosion resistance than type 304 stainless steel. In chlorine environment, 316 stainless steel offers a high resistance to crevice corrosion and pitting than 304 stainless steel.

Type 316 stainless steel is often used in heavy gauge welding applications because the risk of pitting, cracking and corrosion is reduced, while type 304 stainless steel often used in the creation of cookware and in the construction of dairy equipment, such as milking machines.

1.4.10 Cutting Tool Material

A cutting tool is any tool that is used to remove material from the workpiece by means of shear deformation. Cutting may be single-point or multipoint tools. Single-point tools are used in turning, shaping, plaining and similar operation. Milling and drilling tools are often multipoint tools.

Figure 1.1 Uncoated Carbide Tool

1.4.11 Different cutting tool material

1. High Speed Steel

High speed steel (HSS) is a high carbon ferrous alloy consisting of W, Mo, Cr, V, and Co. HSS is generally available in cast, wrought and sintered (obtained by using powder metallurgy technique) form. HSS is inexpensive compared to other tool materials. It is easily shaped, and has excellent fracture toughness, and fatigue resistance. HSS is suitable for use only at limited cutting velocities of 30-50 m/min because of its limited wear resistance and chemical stability. HSS is generally used for geometrically complex rotary cutting tools such as drills, reamers, taps, and end-mills, as well as for broaches. HSS are broadly classified as T-type steels which have tungsten as the dominant alloying element, and M-type steels in which the primary alloying element is molybdenum.

2. Cemented carbide

Cemented carbide is a modern cutting tool material manufactured by mixing, compacting and sintering primarily tungsten carbide (WC) and cobalt (Co) powders. Co acts as a binder for the hard WC grains. The carbide tool have strong metallic characteristics having good electrical and thermal conductivity. They are chemically more stable, have high stiffness and exhibit lower friction, and operate at higher cutting velocities than HSS tools.

But carbide tools are more brittle and more expensive than HSS. They are generally recommended for machining steel. K grade carbides are straight tungsten carbide grades with no alloying carbides. They are used for machining grey cast iron, nonferrous metals, and nonmetallic materials. M grade carbides are alloyed WC grades generally with less amount of TiC than the corresponding P series, and have wider application in machining austenitic stainless steel, manganese steel as well as steel castings. Each grade within a group is assigned a number to represent its position from maximum hardness to maximum toughness (higher the number, tougher the tool). P grades are rated from P01 to P50, M grades from M10 to M40, and K grades from K01 to K40. The performance of carbide cutting tool is dependent on the percentage of Co and grain size of carbide(s).

3. Cermets

Cermets are ceramic materials in a metal binder. They consist of TiC, TiN, or TiCN hard particles held together by a softer binder alloy of Co and/or Ni, Mo. Cermets are less susceptible to diffusion wear than WC, and have more favourable frictional characteristics. Cermet cutting tools are most suitable for the machining of steels, cast irons, cast steels and nonferrous free-machining alloys because they are capable operating at higher cutting velocities than cemented carbides thus allowing better surface finish. However, they have a lower resistance to fracture and lower thermal conductivity, and are more feed sensitive.

4. Ceramics

Ceramics are inorganic, nonmetallic materials that are subjected to high temperature during synthesis or use. They retain excellent hardness and stiffness at temperature greater than 1000 °C, and do not react chemically with most work materials at these temperatures. There are two main categories of commercially available ceramic tools:

i. Alumina-based ceramics comprising of pure oxide, mixed oxides, and silicon carbide (SiC) whisker reinforced alumina ceramics.

ii. Silicon nitride-based ceramics.

1.4.12 Different engineering applications

a. As food preparation equipment particularly in chloride environment
b. Laboratory benches and equipment
c. Coastal architecture paneling, railing and trim
d. Chemical containers including for transport
e. Heat exchanger
f. Woven or welded screens for mining, quarrying and water filtration
g. Thread fasteners

CHAPTER 2

LITERATURE REVIEW

2.1 DEFINITION OF MACHINABILITY STUDY OF STAINLESS STEEL

2.1.1 Effect of Machining Parameters on Cutting Force

According to Ciftci(2005) AISI 316 resulted in higher forces at all cutting speeds employed than AISI 304. The 2.0% Mo present in AISI 316 was considered to be the cause of the higher forces. Zhuang et al.(2010) studied two steel, free cutting austenitic stainless steel and austenite stainless steel 1Crl8Ni9Ti at various cutting speeds ,they find that the cutting forces generally decreased with the increase of cutting speed in the range 10 – 80 m/min. They reached 418 N and 336 N at 10 m/min cutting speed for steel A and B, respectively. And at 80 m/min cutting speed, principal forces were 343 N and 275 N for steel A and B, respectively. S.Agarwal et al. measured both the axial and the tangential components of the cutting force during turning. The chips were also collected for examination of their under-surface and top surfaces in SEM. The cutting edges of the coated tools were examined in SEM to determine the extent of wear.

2.2 EFFECT OF MACHINING PARAMETERS ON THE TOOL LIFE

2.2.1 Influence of the Cutting Speed and Feed Rate

Tekiner et al.(2003) studied the values of flank wear resulting from five different cutting speeds 120, 135, 150, 165 and 180 m/min and three different feed rates 0.2, 0.25 and 0.3 mm/rev, flank wear is decreasing while feed rate is rising from 0.2 to 0.25 mm/rev; and then it is starting to increase when it is rising 0.3 mm/rev. Built up edge values forming on insert used in different cutting parameter were measured by microscope, by doing this, it was seen that cutting speed increased and built up edge value decreased. Astakhov (2006) showed that the tool life decreases with increasing cutting feed. According to Korkut et al.(2003) Tool flank wear decreased with increasing the cutting speed up to 180 m/min. According to Akasawa et al. (2003) copper addition reduced the amount of adhering material on the tool face. It is usually easy in steel-making processes to add copper to steel and copper is known to reduce strain hardening, thus it has the potential to improve machinability. But because copper may accelerate the wear of K-grade carbide tools through copper diffusion into the binder of carbides, it is important to select the optimum carbide tool grade.

2.2.2 Influence of the Depth of Cut

Astakhov (2006) showed that when the depth of cut increases and the uncut chip thickness is kept the same, then the chip compression ratio and the average contact temperature remain unchanged. Hence, any change in increase in the depth of cut would not change the tool wear rate. The depth of cut has very little influence on the tool wear rate when the cutting speed was determined to be optimal for the depth of cut dw = 0.5 mm. Chipping of the cutting edges, evidenced by the SEM examinations, was also found to be responsible for the high surface roughness values.

2.2.3 Influence of the Work piece Diameter

As discussed by Astakhov (2006), the diameter affects the static and dynamic rigidity of the machining system, curvature of the surface being cut, and interaction of the thermal and deformation waves in the layer being removed.