INVESTIGATION OF HARDNESS AND MICROSTRUCTURE IN QUENCHING RECYCLED M2 HIGH SPEED STEEL

This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

By,

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DECLARATION

I hereby, declared this report entitled “Investigation of Hardness and Microstructure in Quenching M2 High Speed Steel” is the result of my own research except as cited in references.

Signature …………………………………….

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Date : 15 January 2021

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for

Degree of Manufacturing Engineering (Hons).

The member of the supervisory committee is as follow:

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ABSTRACT

This research of this project mainly focused on the hardness and microstructure of recycled M2 High Speed Steel. The main specimen of M2 High Speed Steel that has been used is the M2 High Speed Steel that taken from FKP lab and a material considered as an alloy material. Before the analysis of the M2 High Speed Steel is done, a few procedures have been done first. The main process that was experimented on the specimen is the Resistance heat treatment and Quenching. Both of the processes have been done using a significant method and machine that will be discussed in detail in the following chapter. To see and analyse the variation of the process effect, some parameters were set to test the material. By obtaining a bunch of raw data from the experiment, we have differentiated and determine which parameters suit the most with the specimen material. The output or final product of this project is to produce a cutting tool from the treated specimen in the coming project.

ABSTRAK

Kajian di dalam projek ini mengfokuskan kepada kekerasan and mikrostruktur besi M2 high Speed Steel. Spesimen utama yang digunakan ialah besi terpakai M2 High Speed Steel yang didapati di lab FKP dan sejenis bahan besi aloi. Sebelum besi tersebut dikaji, beberapa prosedur harus dijalankan terlebih dahulu. Proses utama di dalam kajian ini yang akan dijalankan kepada besi M2 High Speed Steel ialah proses rawatan panas dan proses pelindapkejutan. Kedua-dua proses akan dijalankan menggunakan cara dan mesin yang akan diterangkan pada bab seterusnya. Untuk melihat dan menganalisis variasi terhadap hasil proses, beberapa parameter akan dijalankan pada bahan tersebut. Hasil dari data eksperimen, pembezaan akan dilakukan dan pemilihan parameter terbaik akan dilakukan untuk melihat parameter yang memberi kesan terbesar kepada bahan. Hasil dari eksperimen ini, bahan tersebut akan dijadikan sebuah alat memotong untuk mesin.

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TABLE OF CONTENT

CHAPTER 1

INTRODUCTION

This chapter will explain and summarize the whole chapter in simple form by overview the background of study, problem statement, objective and scopes of this investigation. The background of study will explains theoretically and based on current issues which only related aspects that will be put into considerations to ensure the research is always in the correct path. The problem statement will explain regarding the current issue, complaints, major problem that have being experienced by the industries or another researcher. The problem statement need to be a facts based on previous researches. The objective will clarify the mission or the goal of this research until the end in order to navigate towards the related topic only. Scopes will clarify the certain limitation that will affect the result of this research.

1.1 Background of study

Cutting tool is one of the major factor that will affect the machining performances as well as the quality of the part produced. Maintaining the quality and minimization cost is not an easy tasks for every industrial sector as most of them need to invest more in terms of financial to make sure the quality aspects is always at the very good level which satisfied the customers. To be list, there are a few type of cutting tool such as, cemented carbide, ceramic, cubic boron nitride, carbon steel, high-speed steel and etc. Two conditions that will describe the applications of cutting tool which is single point cutting tool which the operation involves only one cutting edge such as turning, shaping and planning process. The other one would be multiple points cutting tool which being used in milling process. However, the cutting tool will only have one mission to serve which is material removal through shear deformation. The accuracy, precision, tool wear rate are important factors in machining.

The application of ceramic in cutting tool is widely used as it is very durable to be perform at high temperature and high speed machining. However, the limitation factor such as low thermal inferior shock resistance and low fracture toughness causes it to crack at certain points during machining. Compare to other material, ceramic cutting tool is the most dominant in the aspects of application in machining but due to the weakness, application of ceramic is stopped to a fix level. For this research, recycled M2 high speed steel (HSS) will be tested in order to improve the mechanical and physical properties of the cutting tool that taken from waste or scrap component of end-mill .

A review of previous experiment on the bonding of M2 high speed steel (HSS) using different methods will be a guideline for this research. The method that difference is, a new approach on method to bond which is electrical current activation sintering/resistive sintering. The parameter such time and temperature will be recorded to measure the production rate for sintering process as well as heating rate. For sintering characteristic, a few tests will be conduct such as hardness test, fracture toughness test for mechanical properties, and density, shrinkage, porosity for physical properties.

After the analysis on mechanical properties and physical properties is done, a test on machining performance will be conduct in terms of tool wear rate. This test will be prove whether the composition of the recycled M2 high speed steel (HSS) is able to enhance the hardness and strength of the new M2 high speed steel.

The target or desired product of this study is a high strength recycled M2 high speed steel material with good microstructure surface for multi-propose application whether in cutting tools for machining application

1.2 Problem statement

Nowadays, in the industry that involved a usage of M2 high speed steel (HSS), the user always or normally throw away the end-mill or drill tool after it is failed or worn out. That cutting tools are still fit enough to be recycled. Even though the other part at the other end is still good in condition, it still need heat treatment process to improve its function. This is because the only part that contact with the workpiece when the process of drilling or milling that is fully damaged. So, the material at the other end experienced less damage. In this investigation, we can prove that the material at the other end still can be used and can be heat treated to improve its hardness and strength.

Another problem that should be focus on is, normal high speed steel sintering requires high temperature and long soaking time. This means, to achieve bonding between nanostructures require high temperature and time. At the same time, the whole process normally consume numerous amount of energy especially in terms of electrical consumptions. Indirectly, the whole process could lead to waste in the aspects of costs and time. Next, the application of electrical activation sintering (ECAS) or resistive sintering requires high electrical conductivity material embedded in the structure. Considering M2 Tool Steel is molybdenum based high-speed steel in tungsten–molybdenum series. HSS grade steel M2 is a medium alloyed high speed steel which has good electrical conductivity. This process cannot be done if the material is not a good conductor of electrical current since the concept of ECAS is by applied current and pressure through conduction contact.

1.3 Objectives

- To conduct Quenching on recycled M2 High Speed Steel using resistance heating furnace.
- To analysis the effect of heat treatment on hardness and microstructure.
- To compare the hardness and the microstructure between heat treated specimen and scrap M2 High Speed Steel.

1.4 Scope of study

Considering the main purpose of this investigation is to improve the M2 high speed steel that is taken from waste or scrap. The process are easily can be comprehended with the following points of scopes :-

- The material that will be used to carry out the experiment is only recycled M2 high speed steel.
  - Hot Press Quenching process will be done using resistive sintering machine.
  - Cooling medium that will be used are water, ice and oil.
  - Microstructure and hardness analysis will be done using experimentation process.

CHAPTER 2

LITERATURE REVIEW

Introduction

This chapter will discuss about literature of M2 High Speed Steel sintering in the improving recycled M2 high speed steel, composition of material, type of processes that will be used in investigation and project. An overview of the sintering process will cover the theory of sintering, type of sintering, parameters, and the factors of consideration. Besides, this chapter will review the mechanical and physical properties of M2 High Speed Steel composition in terms of microstructure, hardness and density.

2.1 Materials for cutting tools

2.1.1 M2 High Speed Steel (HSS)

According to Materials (2019), in the Materials and Manufacturing book stated that High Speed Steel (HSS) is a suitable material for cutting tool because of its characteristics which is high hardness and wear resistance. This is because the basic requirement of a cutting tool that the material for the tool need to be harder than the material that need to be cut.

Although HSS is considered an old material compared too much advanced material, it is still a tougher material and can withstand relatively high impact which make it is a commonly used material for cutting tool. HSS also have the abilities to be sharpen multiple times by using only basic abrasive process. This not only elongate the cutting tool life span but will also save the cost for the manufacturer.

The disadvantage of HSS cutting tools are it is not as hard as ceramic cutting tools which means that material with high hardness characteristics may damage the cutting tool or the cutting tool will not be able to cut through the material. It also allow only low cutting temperature thus limiting the type of material that it can cut. After sharpen the geometry of the HSS cutting tools is also permanently changed. This will lead to unfit cutting tool with the carbide inserts making it need to be changed into a new one.

2.1.2 Diamond Cutting Tool

One of the recent cutting tools that is introduced to the manufacturing process is the diamond coated cutting tools. Although the name is diamond cutting tool, it is not made of diamond but the cutting tool is coated with diamond. According to Inspektor, Oles, & Bauer (1997), in the nature environment diamond is one of the material with highest Young's modulus value which means the hardness of the material is relatively high compare to other material. For the heat conductivity, it is highly conductive at room temperature and the coefficient of friction is almost the same or can be compared with Teflon.

With all of this characteristics, diamond is an ideal for coating a cutting tools that need to be used to cut high strength or hardness material. There are 2 types of diamond coated cutting tool which are Single Crystal Diamond cutting tool and Polycrystalline Diamond (PCD) cutting tool. (Materials, 2019)

In order to evaluate the diamond purity and bond characteristics, the Raman spectroscopy is done. This evaluation will determine the rates of molecular vibration frequencies to the inter-atomic bond between the diamonds in the coating. (Hu, Chou, Thompson, Burgess, & Street, 2007)

According to Hu et al, (2007) also said that to counter the adhesion problem during the interface combination, multiple adhesion technique has been applied in order to enhance the adhesion strength of the diamond coated cutting tools. After the process is done, Rockwell hardness test is done to evaluate the level of hardness of the cutting tool.

Another method to produce the diamond coated cutting tools is the Physical Vapour Deposition (PVD). PVD coating process include all of the process that the coating material is physically removed from the origin source by evaporation or sputtering. Some of the example for the PVD process that is commonly used in coating cutting tools are Magnetron sputtering, electron beam evaporation, arc evaporation and activated reactive evaporation. (Gupta, Ramdev, Dharmateja, & Sivarajan, 2018)

Chemical Vapour Deposition or also known as CVD also can be applied in order to produce this type of cutting tools. The coating process that has been done by CVD will have variety of outputs in terms of diamond purity, micro or nano structure, and the interface with the substrate. (Hu et al., 2007)

The example of CVD process are atmospheric pressure CVD, metal-organic CVD, low pressure CVD, laser chemical CVD, photochemical vapour deposition and many more. This various types of CVD process have their own advantages and disadvantages according to the application and suitability of the coating material and the material that need to be coated.

As mentioned earlier, diamond coated cutting tools are suitable for ultrahigh precision work for example in the production of aircraft production, national defence product and economic constructions. All of this application required high precision dimension and good surface finish. This is where the diamond cutting tools plays it part in the manufacturing process.

In order to measure the diamond tool efficiency and accuracy Electron-Beam Induced Deposition (EBID) is introduced. EBID is one of the application in scanning electron microscope (SEM). The EBID has given an accurate reading because of it can be precisely placed on a selected area. (Shi, Lane, Mooney, Dow, & Scattergood, 2010)

Another method to determine the accuracy and precision of the diamond coated cutting tool is by using the Atomic Force Microscope (AFM). This technology gives the output or reading in form of 3D imaging in nanoscale. Although there are some limitation and difficulties in order to perform this process for example, the AFM probe tip dilation with the diamond cutting tools edge may lead to error. This occur mainly during the evaluation of cutting edge accuracy and precision. (N. Yang, Huang, & Lei, 2018)

2.1.3 Tungsten Carbide Cutting Tools

One of the most important attribute to a cutting tool is the tool life of the cutting tool itself. This is the reason that make carbide cutting tools a favourite tools for most machining process. Other than it can save more cost due to its longer life spend, it is also will affect the production efficiency for machining. Some of the characteristics of the tungsten carbide cutting tool or also known as WC-Co are it has a high hardness, wear resistance, and a thermal structure stability. (Sert & Celik, 2019)

Due to its hardness, the range or variety of material that it can machine are vast. According to Sert & Celik, (2019), WC-Co is one of the material that are suitable for machining titanium. As we all know, titanium is one of the hardest material that need to be machine. However, the machining of titanium is required mostly in the aviation industry.

To compare Tungsten carbide with HSS in most of the characteristics that are needed for cutting tool application, Tungsten carbide are more superior compare to the HSS. One of the special characteristic that Tungsten carbide have is the property of hot hardness or also known as red hardness. This ability benefits the Tungsten carbide as it would retain its hardness, strength, and wear resistance even if it is used at elevated temperature. (Materials, 2019)

In order to produce a cutting tool using carbide, there are a few process that need to be done. The carbide material comes in the form of powder as it will be easier for the material to be manufactured or process into another form or application. This material can be acquired easily and the price are not very expensive.

Other material that need to be used are binder in order to hold the powder together making it stronger and more ductile. This will make it considerably tough composite material as its now contain two type of material which is the carbide powder and the binder. (Materials, 2019)

The material or binder that are often used for the tungsten carbide cutting tools is the cobalt. The function of cobalt is to ensure the surface of the tungsten carbide is “wet” so that it will strongly adheres the particle together. With all the attributes of the cobalt and carbide bind together it will allow the cutting tool suitable for high temperature application.

As mention before, tool life will affect the quality or outcome of the final product and the main issue here is the life spend of the cutting tool itself. In this part, wear experimentation or research is very crucial. Some of the wear that often occur in tungsten carbide cutting tool are abrasion, adhesion, oxidation and diffusion. (Arsecularatne, Zhang, & Montross, 2006)

According to Arsecularatne et al, (2006) in his journal stated that most of the wear mechanisms are affected by the process parameters itself. The table below will show the process parameters and the wear that it will produced.

Process parameters	Tool Wear Effect
Low speed or temperature	Abrasion
Moderate speed and temperature	Adhesion
High speed or temperature	Diffusion

Table : Process parameters and tool wear effect.

However, the all of the wear stated above are also depending on the cutting condition, cutting tools and the work piece material. Not all of defect are the same in each process. So, in order to avoid this type of wear, the correct tools need to be chosen for the right work piece with the right process parameters.

Researchers have done a lot of experiment and upgrade to the tungsten carbide in order to enhance the material characteristics so that the life spend of the tool increase. One of the method that has been used is the Cryogenic Treatment for tungsten carbide cutting tool. This treatment recently used to improve properties of various material. So what is cryogenic treatment actually is?

Cryogenic treatment is a process that carried out directly after the quenching process and then followed by tempering. The started after the quenching process as the material will be soaked for about 8 to 24 hours according to the material and application. It is soaked in a liquid nitrogen at the temperature of -196℃. This process has shown significant improvement on the properties of the material in term of microstructure and mechanical properties. (Sonar, Lomte, & Gogte, 2018)

Material that does not undergo cryogenic treatment usually encounter several types of defects such as crystal defects, lattice defects, and residual stress. All of the defects can be counter or balanced using the cryogenic treatment which made this process is ideal to produce a better tungsten carbide cutting tool. (Sonar et al., 2018)

2.1.4 Cubic Boron Nitride Cutting Tools

Cubic Boron Nitride is an efficient cutting tools due to its high hardness characteristics. It can be divided into 2 major crystalline poly types which are hexagonal and the zenc-blende structure. The hexagonal crystalline is present as h-BN while the zencblende structure is represent by c-BN. The basic characteristics of this material are very light material, high hardness only second compare to diamond, high strength, wear resistance and high radiation resistance. (Soltani et al., 2010)

First, the Boron Nitride comes in the form of hexagonal and need to be transform into the cubic phase. There are various way in order to achieve this phase and usually take place at elevated temperature which is above 1000K and pressure at 4GPa. By performing Chemical Vapour Deposition (CVD), Physical Vapour Deposition (PVD) or pure ion beam deposition also can change the phase of the boron nitride. (Soltani et al., 2010)

According to Werninghaus, Hahn, Richter, & Zahn, (1997), the size effect of Cubic Boron Nitride also will give attribute to the material bond and structure. This changes can be determine by running the Raman spectroscopy investigation. From this investigation, the researcher has found that the optical phonons is increasingly asymmetric towards a lower frequency shifts. In other words, the bond will become broader and weaker when the crystal diameters decrease.

As mention earlier, the Cubic Boron Nitride is among the strongest solid element which only second after diamond. The hardness test has been done on the material and the outcome of the test is very outstanding. The Vickers hardness test has been done and the acquired reading is 50GPa. This hardness test is measured using the diamond indentation method which make the reading are relatively precise. This is because in the periodic table of elements boron known as polymorphs and it is super hard. (Qin et al., 2012)

When the material is stated it has the hardness compatible to the diamond, machinist or manufacturing industry start to change the usage of diamond cutting tools Cubic Boron Nitride cutting tools. This is because Cubic Boron Nitride have numerous numbers of excellent characteristics that can make it a challenge to the diamond cutting tools. Its physical and chemical properties makes it even better to be use in the manufacturing industry. Some of the properties of this cutting tools are high chemical resistance and good mechanical properties. (Islak, Kir, & Çelik, 2013)

This statement has been proven by other researcher as the Cubic Boron Nitride has been used in the form of insert to machine a hardened work piece. For example, AISI 52100 bearing steel, AISI H13 hot work steel, AISI 4340 low alloy steel and others are used as work piece. The simulation of turning these types of work piece has been done and the insert of Cubic Boron Nitride is used. (Qian & Hossan, 2007)

Work Piece	Numerical Simulations Evaluation
AISI 4340	Highest cutting force
AISI 52100	Highest feed force
AISI D2	Lowest cutting and feed force

Table : Numerical evaluation with same cutting condition but different material.

If the machining of these type of materials with the use of conventional tools, tool wear will be happen quickly or in other word shorten the tool life. This is due to the high temperature when machining occur because of the work piece hardness making the tool wear even faster. The other factor is the contact of work piece and cutting tool leads to high adhesion making the cutting tool wear. So, to machine high hardness material Cubic Boron Nitride insert is suitable compare to conventional tools. (Qian & Hossan, 2007)

The surface roughness of work piece that has been machined using conventional and Cubic Boron Nitride cutting tools also have different due to the machining parameters itself. When using the Cubic Boron Nitride cutting tools, the factors that mostly effect the surface roughness is the feed rate of the process. When the AISI 1050 hardened steels is used as work piece, the average surface roughness that is acquired is 0.823 µm. This shows that the Cubic Boron Nitride insert is suitable for high precision and accuracy product machining. When the cutting parameters is altered a little bit which is the feed rate is lowered, the value reduced to 0.55µm. It shows that the surface roughness can be control using the cutting parameters. For example the customers does not demand on a high surface finish quality the feed rate can be increase to speed up the process, but if the surface roughness need to be high quality it is also achievable using this type of cutting tools. (Sahin & Motorcu, 2008)

In machining hard material or work piece, one of the most common factor that will affect the output or machining quality is the temperature. The temperature not only effect on the work piece, but the cutting tools also will be affected. To determine the hardness of the Cubic Boron Nitride cutting tools, experimentation can be done. The temperature will be increased then indentation method or Vickers hardness test will be done. From time to time, the change of hardness can be seen based form the hardness reading. The experiment shows that high temperature does effect the hardness of the insert but only at small scale or level because the insert itself need to be heated up to 1000K to change it phase from hexagonal to zenc-blende structure. (Harris, Brookes, & Taylor, 2004)

From all of the explanation above, it shows that the Cubic Boron Nitride cutting tools is one of the most ideal cutting tool available in the industry nowadays. It is because its ability to machine either high end product or a normal spec product, high hardness material or conventional material and many other related factors.

2.2 Hardening Process

In this part of literature review, we will discuss about hardening process that are usually used or done in the industry for cutting tools. Firstly, we need to know the meaning of hardening process. Hardening process is a metallurgical metalwork in order to increase the hardness of a material. Basically, the hardness is directly proportional to the yield stress at the affected location. In other words, the harder the material, the higher its ability to resist from plastic deformation.

2.2.1 Annealing Process

The annealing process is consider a standard and normal hardening process in the industry. This process is capable of hardening various types of material including metal and ceramic. There are also a lot of stages in annealing and for full annealing process, the material is heated until the temperature of the material is slightly above the critical value. Then, this temperature will be maintained for a period of time. The time of the temperature maintained is according to the material itself. This will allow the material to form a fully austenite or austenite cementite grain structure. (Tuong, 2018)

After the process of annealing, there will be effects on the material either to their characteristics or properties. According to Khan, Zulfequar, & Husain, (2002), one of the annealing effects to material is increasing the size of grain in the material. This process has been done on Tellurium (Te), a chemical material which has brittle characteristic. In the experiment, Te is in the form of thin sheet. As mention before, the increasing size of the grain is the proof that annealing is affecting the crystallization of a material.

In another experiment, annealing process has been done on AISI431 grade stainless steel material to see the effect of the process on the material. (Subbiah & Kumar, 2018). The results of the experiment are as below;

- Fine grain of the martensite structure has been converted into coarse grain structure. This leads to increase of ductility and softness on the specimen.
- Untreated specimen tends to wear faster due to the original characteristics of the stainless steel which are hard and brittle.

According to Lin, (2015), annealing process only lead to particle size only. This experiment is done on Copper (1) Thiocyanate (CuSCN) in form of thin films.

As for the surface roughness of the material after annealing process, experiment is done on the 4H-SiC which is one of the silicon carbide types of material. Annealing process has been giving a positive of results for the surface roughness of the material. The change of surface roughness can be seen significantly on the material. After the process is done, the surface roughness of the SiC has reduced dramatically from 6.6µm to 3.8µm. This result proves that annealing is suitable for high precision product or production. This is because the surface roughness is also treated when the temperature of annealing process is up to 1700℃ due to the electrical activation up to 75% can be achieved. (Hailei et al., 2011)

According to Kozlovskiy, (2018) on properties of Ni nanotubes, structural properties of a material also can be altered using the annealing process. When the average crystalline size increases this proportionally increase the size of the material. Other structural change that we can see from the annealing process effect is the lattice parameter and the appearance of new phases of structure. From 400℃ to 600℃, the peaks intensity of the material decrease sharply and the peak shape is forming from the symmetrical shape can be seen.

In term of electrical properties, the process also can be used to achieve certain properties that is required by the users. When Zinc Oxide nanostructures material undergo annealing process, the electrical resistance of the material is reduced thus increase its conductivity. In other words, annealing process also can be used to perform hardening process for electrical appliances and product. (Luqman, Napi, Mohamed, & Ismail, 2019)

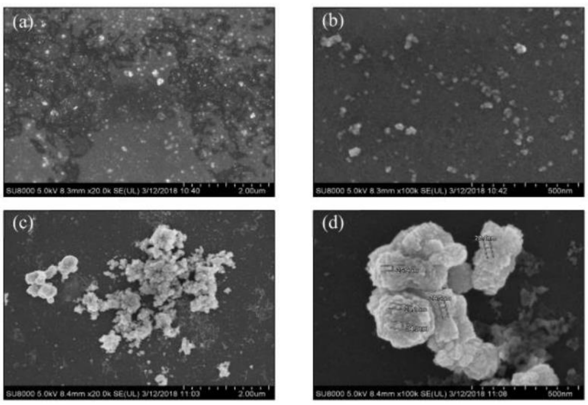


Figure : Image a is the sample before annealing process while b, c and d is when annealing is done with different level of magnification. (Source: Luqman et al., 2019)

2.2.2 Normalizing

Another method of metal hardening is the normalizing heat treatment which is also one of the famous heat treatment in the industry. According to Pandey, Mahapatra, Kumar, & Saini, (2018), normalizing process is altering the characteristics and properties of material. This alteration can be used in our advantage if we decide to increase the strength and hardness of the material. This is because the normalizing process can be done at the temperature that is not so high so it can be done easily in the industry. In the experiment done by Pandey et al., (2018), the best temperature for the normalizing process material P91 steel weldments is at 1050℃. At this temperature, the material will obtain a good combination of strength, ductility and microstructure.

For the microstructure of a material that has undergo normalizing process, the residual austenitic and packet grain size has been increased. The enlargement of the grain size has been significantly affecting the properties of the material in term of strength and ductility. This enlargement can either be an advantage or disadvantage according to the material application or appliances. (Fukumoto et al., 2013)

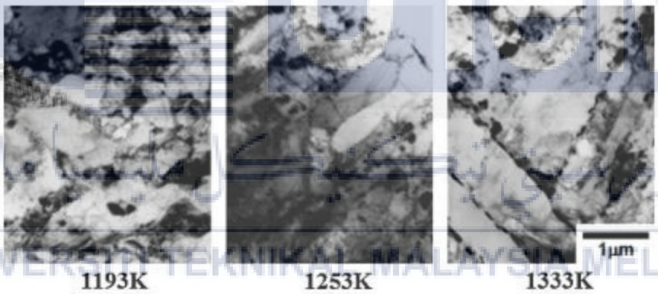


Figure : Effects of different normalizing temperatures to the treated material.
(Source: Fukumoto et al., 2013)

In the study of microstructure and tensile properties of 1045 steel with (NbTi) C nanoparticle by Zhu, Xu, Qin, Xiao, & Liao, (2018), the normalizing process has proven significantly in improving the mechanical properties of the material. This improvement can be seen through a comparison between a treated material and untreated material. The (NbTi) C nanoparticle has significantly affecting the austenite grain growth.

For the surface roughness affect in normalizing process, normalizing heat treatment will increase the quality of the machined part. This occur due to the grain size increment thus making the material easier to be machine. When the material is easier to machine, the surface roughness of the machined part will be increase because there are less friction and less hardness the cutting tools need to cut through to perform the cutting process. So, this will automatically increase the quality of the surface roughness when the material undergo prenormalizing process. (Sanusi & Akinlabi, 2018)

Normalizing process also can be done with the present of high pressure which has been done to check the microstructure and creep strength of a Cr steels. When normalizing is done under high pressure of 4GPa, a martensitic microstructure has been obtained. If the process is done at the atmospheric pressure different type of microstructure can be observe. At atmospheric pressure, ferrite microstructure with the present of coarse particle can be seen on the surface of the material. (Kimura & Yamaoka, 2004)

For the production of cutting tools, normalizing process is not consider a suitable process. This is because the heat treatment process will enlarge the size of grain as mention before thus making the material softer but for normalizing process with the influence of pressure, certain material also can be harden by this process. So, for the application of cutting tools, normalizing need to add with high pressure to increase the hardness and ductility of the cutting tools.

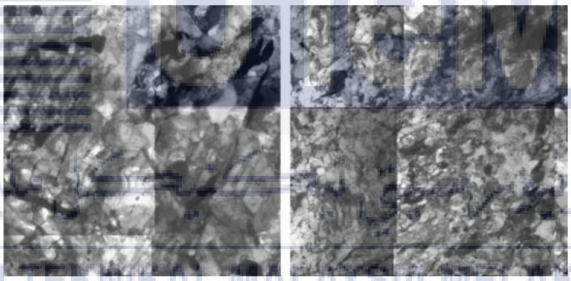


Figure : Effect of pressure to the microstructure of the material when undergone normalizing process. (Source: Kimura & Yamaoka, 2004)

2.2.3 Resistive Sintering

Flash sintering or also known as resistive sintering is a hardening process that is mostly used for hardening ceramic material. Although it's special ability to harden ceramic it is also able to harden metal using the same method and setting. The main characteristic of this process that it uses electrical unlike other hardening process that use fire as heating element. By using electrical as main heating element, it can save cost in term of economic, environmental and energy. (Biesuz & Sglavo, 2019) According to Biesuz & Sglavo, (2019) the list below shows the main operating condition for resistive sintering:-

- AC/DC current.
- Electrode material.
- Powder conductivity. (For ceramic material)
- Pressure.
- Treating time.
- Atmosphere.
- Sample geometry.
- Furnace temperature.
- Current density and particle size.

Another technology that has been added to resistive sintering called Electric Current Activated Sintering (ECAS) also can be applied. This application is suitable for producing a homogeneous micro-structure material. By using the ECAS resistive sintering process this type of material can be produced at a lower temperature and shorter time compare to a conventional sintering process. This is due to the electrical flow helps the alteration of microstructure of the material until it reaches the macroscopic level. (Bernardo et al., 2019)

In other experiment, sintering has been done on a material known as Magnesium Diboride to determine the characteristics of the material after the process is done. The results of the experiment has shown significant change in the material properties and characteristics. The core hardness of the material has increased. This is because the material has undergone a better and improved compacting in the mechanical process. When pressure is applied to the resistive sintering process the material show there are large increment in term of density and hardness after the process is done. (Dancer et al., 2009)

As mention above, one of the most important factor in sintering is the temperature of the process itself. The temperature will affect the structural, magnetic and electrical properties such as conductivity, resistivity and others. This is a Plasma Activated Sintering (PAS) process that has been carried out on a ceramic material. The results shows that after the process is done as the temperature of the sintering process increased the magnetization of the material has decreased while the resistivity of the material increased. (Li et al., 2018)

When there are usage of electricity, the process can't escape from the effects of electromagnetic fields. According to Rybakov & Volkovskaya, (2018), when the process is done the particle of the material are electrically insulated to each other. This is due to the metal properties that absorb the electromagnetic field and store it inside the particle making it an insulated particle. However, the electromagnetic field make the resistive sintering process suitable for sintering large variety of material either metal or ceramic.

External electrical field can also assist the sintering process. There are many benefits of this activation such as it enable sintering of higher densities material in a shorter time period. This is compared to a conventional sintering process. Large variety of powder also can be sintered when the electrical field is activated. Finally, the external electrical field assisted sintering required no additives, no cold compaction, and shorter processing time and can be done without atmosphere control to sinter the material. (Groza, 2000)

2.3 Experiment Parameters

For this part of literature review, we will discuss about the main parameter of the experiment for this project. This parameters will determine the successfulness and effectiveness of the experiment. In this project, there will be 2 main parameters that need to be analyse which are the hardness and microstructure of the material. Both of the parameters will be analyse on the material before and after the experiment has been done. By measuring before and after the experiment done, we can determine the efficiency of the experiment and analyse either the final meet the requirement of the project or not.

2.3.1 Hardness

According to Test, (2003) the ability or property to resist plastic deformation is known or labelled as hardness. This property usually tested by penetration of the material using certain test. Other than plastic deformation, hardness also contribute to the material resistance to bending, scratching, abrasion or cutting. In other words, the higher the hardness of a material, the harder for it to bend, scratch or cut.

Figure 2. 9: Example of micro hardness test machine that will be used. (Source: FKP lab)

There are a few basic hardness test that are available in current industry:-

- Brinell hardness.
- Meyer hardness.

• Vickers hardness.

• Rockwell hardness.

• Micro hardness test

Each of the hardness test have their own units and indicator to measure and analyse the hardness of the tested material. The indenter for each test is also different according to its function or application. However, there are 3 general types of hardness measurement:-

• Scratch hardness is tested to determine the ability of the material to scratch on one another either with the same material or not.

• Indentation hardness is the most famous test in order to determine the hardness of a material especially metal material.

• Rebound or dynamic hardness is a test where an indenter is dropped on the tested material and the hardness is expressed as impact energy.

However, in this project we will focus on the indentation hardness test using the Vickers test to determine the hardness of the material. This is because Vickers test hardness can produce or give output in an instant which means it will save more time to get the analysis of the harden material. Other than that, Vickers test is a user friendly test as it is free from personal error. It has the ability to trace a small level of changes in term of hardness of the material. This is very important because in this project small amount of changes also can be count as an output.

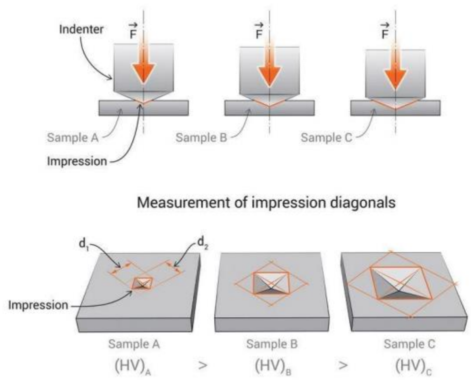


Figure : Basic principle of Vickers hardness testing method. (Source: Google)

Vickers hardness test is a test that applied load to the surface of the material. The load is applied through a diamond pyramid shape. The base of the diamond pyramid is a square shape base and has the angle of 136° in each of the pyramid surfaces. When the load is applied through the diamond pyramid shape or also called as indenter, it will cause indentation to the surface of the tested material. It will then leave an impression on the surface of the material. The depth of the indentation will be used to determine the hardness of the tested material. (Lima Moreira et al., 2016)

According to Lu et al., (2019), the effect of cutting parameter can also affect the micro hardness of the material. In the experiment of micro-milling process for a material called Inconel 718, when the spindle speed of the machining is increased the micro hardness of the material is decreased. However, when the cutting depth and feed per tooth is increased the micro hardness of the material also increase. This parameter however does not affecting this project experiment as the material which is Boron steel 22MnB5 will only undergo heat treatment. Machining will not be done in this project but for further research which is to transform the treated Boron steel into cutting tool, this parameters must be studied properly.

According to Nayan, Mahesh, Prasad, Murthy, & Samajdar, (2019), hardening process leads to the material matrix hardening index increase. This is because the hardening process happen due to the anisotropic or isotropic precipitates. When this occur, automatically the hardness of the material will increase thus making harder to bend, scratch or penetrated.

In other research by Lee, Stoughton, & Yoon, (2018) anisotropic hardening is also known as directional hardening. This experiment is done by applying monotonic loading condition, however the ability of the tested material has given a bad result. So the researcher has change the load into a proportional loading condition. From this experiment, we can see that there are many condition or situation that can be altered in order to get a good analysis of the hardness of the material.

Hardness of a material also can be increase by using binders in the material. This has been done to a cemented tungsten carbides as the material has been added with binder. The binder that has been used is the Cr-Ni alloy binder. The material shows increasing hardness property by increasing the strain rate after binder added into the material. So, when the material with binder is compared with the material without the binder there are significant different in term of hardness in both specimen. This is because the larger grain size of the binder giving the material a higher increment in dynamic over the quasi-static hardness. There are about 60% of hardness increment in the material after the binder is added. (Hanner, Pittari, & Swab, 2018)

2.3.2 Microstructure

In material investigation one of the most important characteristic or property is the microstructure of the material itself. Microstructure is the structure or fine surface on a material. This characteristic is very fine or small that it can’t be seen without the helps or usage of microscope. By using microscope, it requires 20 times magnification to reveal the microstructure of the material. There are many properties that are related or contributed by the microstructure such as hardness, surface roughness and material endurance from heat or environment.

Figure : Example of optical microscope that will be used in this project. (Source: FKP)

As mention before, the microstructure is affecting the properties of the material. According to Sandlöbes, Korte-Kerzel, & Raabe, (2019), when material such as titanium alloys (Ti-Fe) undergo a heat treatment the value of the material properties change. After the heat treatment process is done, the quenching process follow up and in this state the change of microstructure can be observed. The α+β region microstructure change as the Fe element in the material is partitioning. This led to the refinement of microstructure and proportionally increase the strength and hardness of the material.

In another experiment, the results shows that the microstructure of the material affecting the surface roughness of the material itself. In this experiment, the roughness and density is highly affected by the laser power and scanning speed. As the speed of scanning increase the roughness increased but when the laser power increased the surface roughness decreased. This is due to the melting track differ when this 2 parameters changed. The scanning speed changed due to the change of microstructure. The change is in form of equiaxed grain to mixed equiaxed columnar grain. This lead to the increment of scanning speed. (Wang, Xiao, Tse, Huang, & Zhang, 2019)

Another properties that can be alter by altering the microstructure is the fracture toughness and ductility. According to X. Yang et al., (2019), a material known as BT25y titanium alloy undergone a double annealing process and the microstructural evolution or changed is studied. During first annealing, the temperature is between 900°C to 930°C while the second annealing the temperature is reduced to 600°C. As for the ductility, significant change can be observed as the nucleation crack resistance depend on the effective slip length and the crack propagation resistance. This is where the microstructure take place as in the α phase morphology the α colony size and β grain size is the main properties that affecting the effectivity of the slip length. As mention above, the slip length will affect the ductility of the material. Thus the microstructure of the material is affecting the material ductility as it affecting slip length that determine the nucleation crack resistance of the material.

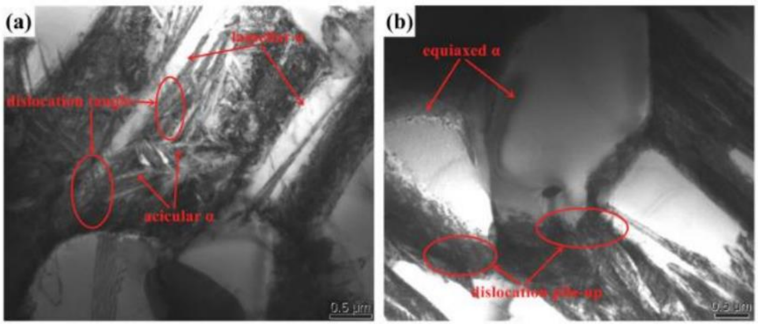


Figure 2. 12: Example of the phase boundaries which a is the lamellar α while b is the equiaxed α. (Source: X. Yang et al., 2019)

For the fracture toughness of the material, there are 3 main factors that affecting the fracture toughness. These 3 main factors are all related to the microstructure of the material which the lamellar are α is distributed disorderly, the grain size of the β and the α layer grain boundary continuity. All of this microstructure change after the double annealing process is the main cause that change the ductility and fracture toughness of the material. (X. Yang et al., 2019)

Finally, the properties that is affected by the microstructure is the tensile stress or strength. According to Liang, Sun, Zhang, Wu, & Chang, (2019), the experiment is done by applying heat treatment on the material which is TiAl4V at 800℃, 850℃ or 900℃ for 4 hours. The material is cooled using air-cooling technique to allow the microstructure change into lamellar α and irregular β. After cooling process is done, observation on the material shown that the material contain mostly β and lamellar α at the finest level. This lead to the material have the best ductility rate and an ultimate tensile strength which is in between 1033MPa and 1069MPa.

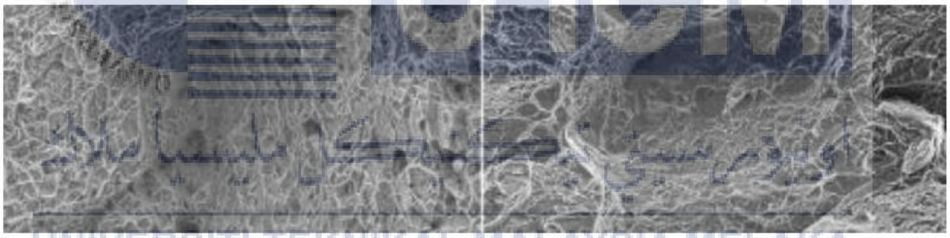


Figure 2. 13: Example image of tensile fractographs under the view of microscope. (Source: Liang et al., 2019)

CHAPTER 3

METHODOLOGY

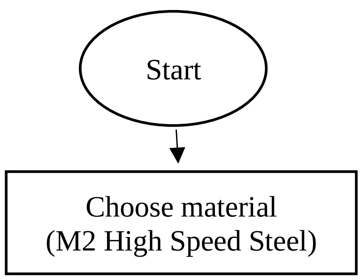
3.0 Introduction

This chapter compacts with the methodology that will be used in this investigation. In discussing this subject matter in detail, this chapter is consists of five main sections which are: research method, research setting, research sample and sampling procedures, instrument of the investigation, data collection and data analysis.

3.1 Process Flow Chart

We have placed the specifics of the experiment into a flow chart to ensure that the steps can be easily understood. By this method, it is easier to track the current progress of the experiment and if there any obstacle or error we can know which steps that need to be repeat in order to get the desired output. In the process flow, the elements that will be covered is the material preparation phase, performing the experiment phase, machine capability phase and analyzing phase. The most critical phase of the project is the experimental period, since most of the machine's capacity and performance will be decided by this stage. So, in the experiment phase some parameters will be determine in order to obtain the desired output by applying the most efficient technique and parameters.

The output desired of this experiment is to produce a cutting tools from a recycled M2 High Speed Steel (HSS). The specimen is produced from a scrap of M2 High Speed Steel (HSS) and cut by using EDM Wire Cut Machine. Next, hot press heat treatment process will be done using a resistive sintering machine that required a furnace to perform the heat treatment. As the temperature of the resistive sintering machine is proportionally increased as the time increase, the most important parameters of this experiment is the duration or time of the heating process. To make the it easier to be understood, the method of this experiment will be illustrated in a flow chart in figure below.



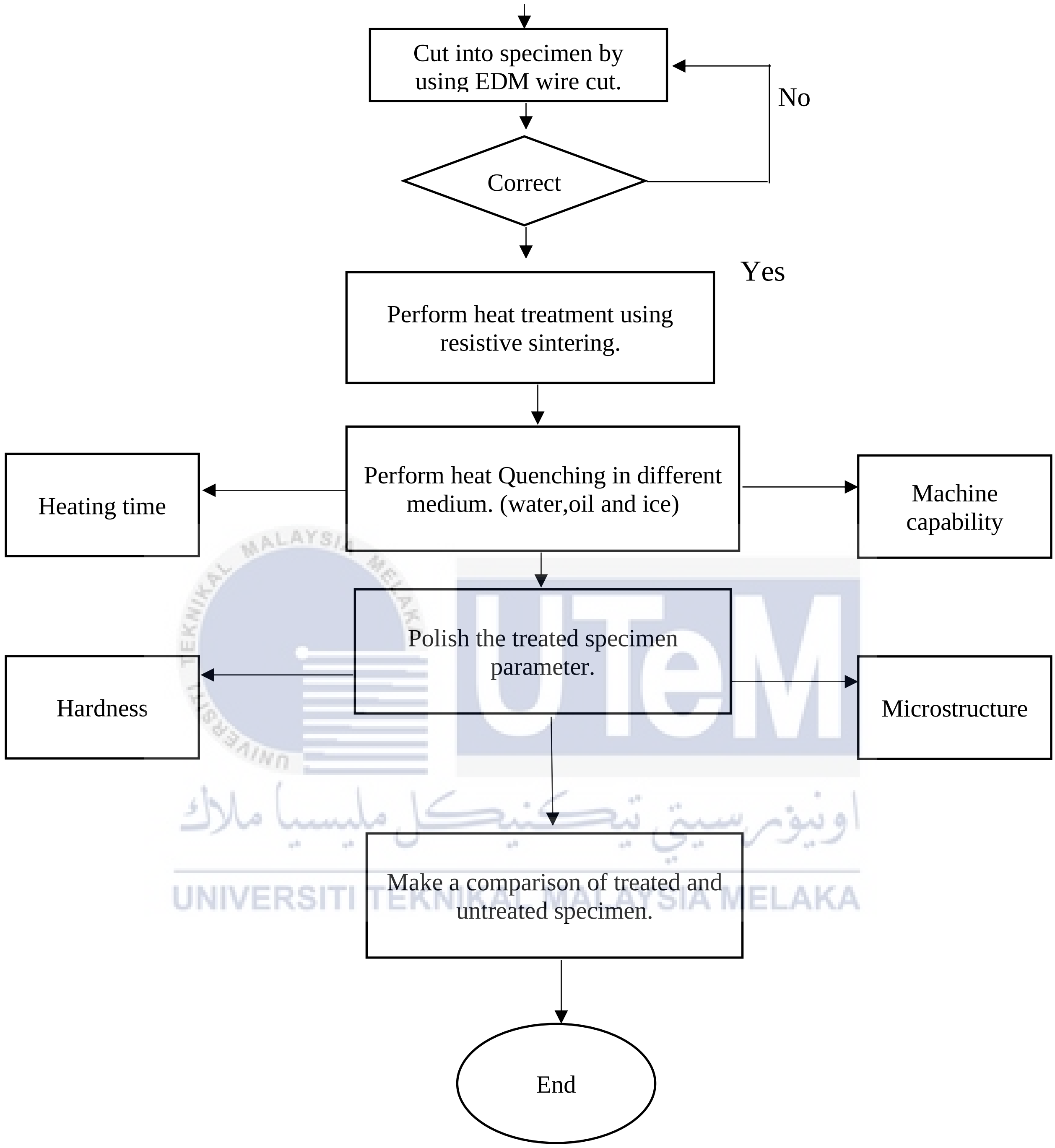


Figure 3.1 : Process flow chart

3.2 Material preparation

After the material for the project has been decided, the material comes in form of round cutting tool which in this case the recycled M2 High Speed Steel (HSS) comes in form of round milling or drilling bit. So, the bit need to be cut into a smaller or desired shape first before the other process can be continued. To perform the cutting process, we have used the EDM wire cut machine. By using this machine, we can get a precise dimension of the cutting tools. This important as we don't want the variation of size affecting the final analysis which is the hardness and microstructure.

The size of the specimen will impact the final analysis because the heat will need to spread wider as the size of the specimen is greater compared to the other specimen. Thus, making some of the area is not heated properly even though the heating time is same. So, specimen size variation need to be avoided.

To ensure that all of the size of the specimen is within the specification, after the cutting process is done using the EDM wire cut machine the size of the specimen is checked using the digital vernier caliper. The digital vernier caliper is used as it is more accurate than the normal one.

Figure 3.2 : Digital Vernier caliper (source: Google)

Before it can be continued to another phase, all of the samples must meet the specification, as the tolerance given for the sample is ± 1 mm. If the specimen is not specified, the specimen will be rejected during the final analysis to prevent variation.

Parameter	Dimension (mm)
Thickness	1.76

Table 3.1 : thickness of the specimen.

As the specimen is taken from the same drilling or milling bit, the diameter of the specimen is not the parameter that we need to control during the preparation of the specimen.

Figure 3.3 : EDM wire cut machine. (Source : Google)

Table below will show the parameter to cut the Boron steel sheet into required dimension using the laser cutting machine above.

Parameters	Values
Pulse on time	117 μs
Pulse off time	50 μs
Pulse current	160 A
Gapset voltage	30 V
Wire drum speed	4 mm/min
Wire tension	8
Cutting speed	3.66 mm/min

Table 3. 2:EDM wire machine setting to cut M2 HSS. (Source: Effect of wire-EDM process parameters on cutting speed –Jayakumar Vijayarangan)

3.3 Determination Of Machine To Perform Heat Treatment

Then the project begins with the process of the hot press quenching. In order to solve such issues that have been counteracted by using a conventional hot press system, we are agreed to use resistive sintering for this project. The following table shows the problem encountered by the existing hot press system and the counter measure of the resistive sintering use.

Resistive sintering	Hot press machine (Furnace)
Direct contact of heating element and surface of specimen will lead to less energy and shorter time required to complete the process.	Large furnace used even for small specimen. Thus, requires more time and energy to complete the process.
Small amount of heat release when lifting the heating element which will be safer for the worker.	Extreme heat contact with worker when opening the furnace door.
Suitable for small product, unit or job type production or components.	Suitable only for large product, mass production or components.

Table 3. 3: Different usage between normal hot press machine with furnace and resistive sintering.

After performing the comparison between this 2 machines, we have decided to use the resistive sintering machine as our main machine to perform the heat treatment process to the specimen. The size of cutting tools that we expected as the final results also is relatively small making it suitable to be processed using this type of machine.

The process also will allow us to determine the capability of the machine as it is new to heat treatment process. The main parameter that will be test and will determine the capability of the machine is duration of the process. We can determine its capability by seeing whether the machine can withstand higher heat produced when the process time increased.

The duration of heating also will affect the hardness and microstructure of the M2 High Speed Steel. The analysis of both machine capability and the final product which is the cutting tools of the M2 High Speed Steel (HSS) will mostly determine by the time factor.

For the quenching process, various type of medium will be tested after the heat treatment process is done. This is to determine which medium suit the most to enhance the properties of the High Speed Steel (HSS). As one of the objective of this project is to improve the recycled M2 High speed Steel in cutting tool application, quenching is one of the most important element in hardening process. So if we can select the best quenching medium, we can increase the capability of the recycled M2 High Speed Steel (HSS).

Figure 3. 4: Comparison of Hot Press with Furnace machine and the resistive sintering machine.

Various type of quenching medium can be chosen but in this project the scope have scale down the type of medium that can be tested due to several issue such as safety and availability.

The list below shows the quenching medium that will be tested for this project:-

- Water
- Oil
- Ice

3.4 Preparation Of Experiment

After selecting the process for the hardening of the recycled M2 High Sped Steel, the method to perform this experiment need to be clearly understand. This is the importance of selecting phase before going into the experimenting phase. It is because the selecting phase will determine the steps to perform the experiment phase.

The flow chart below will show the steps to perform the experiment that will determine the final analysis for the recycled High Speed Steel hardness and microstructure.

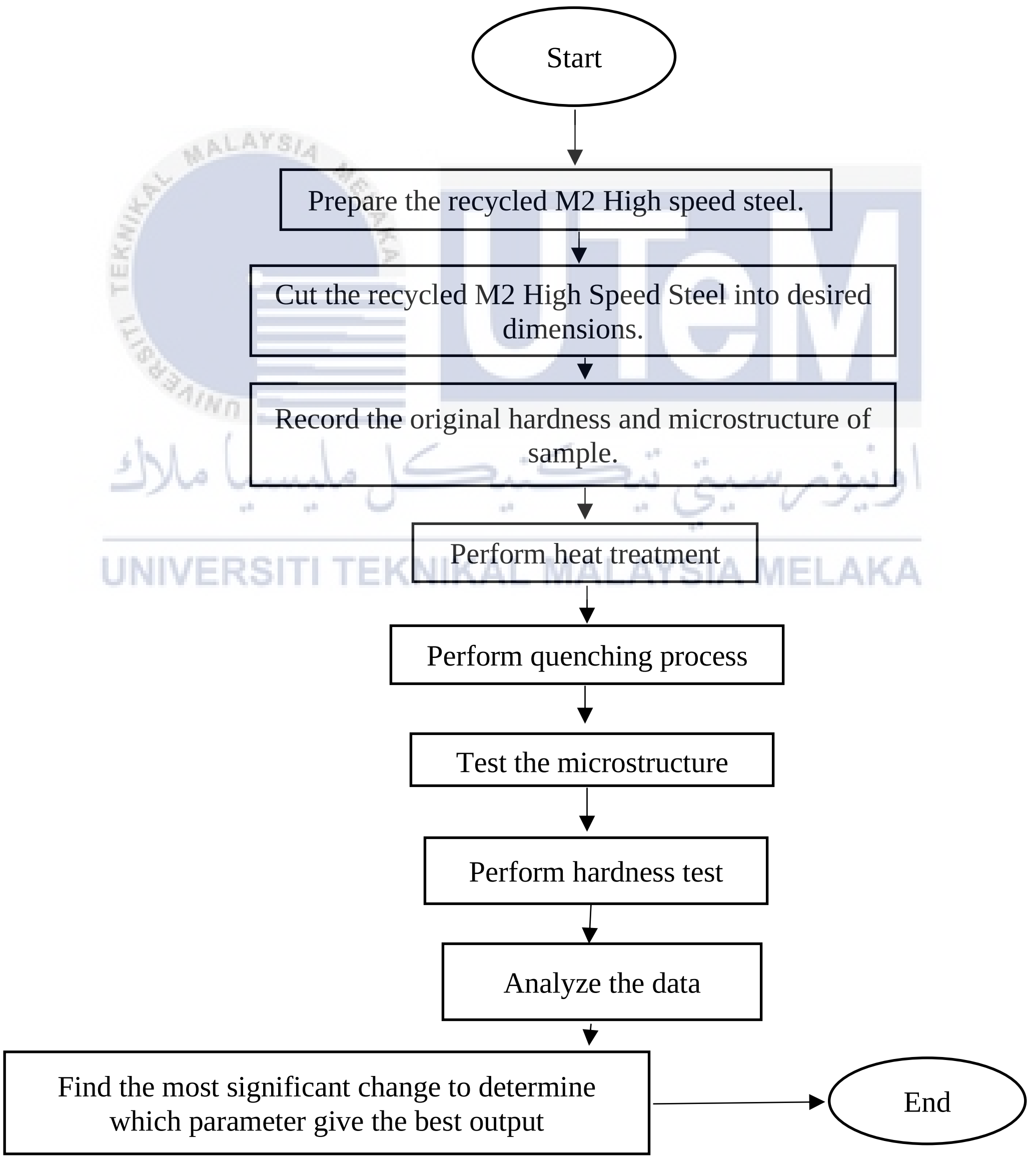


Figure 3.5: Flow chart of the investigation

3.5 Duration of Heat Treatment and Quenching Medium

3.5.1 Heat Treatment (Resistive Sintering)

As mention above, process duration is very crucial in this project as it will determine the final product of recycled M2 High Speed Steel (HSS). So, the project requires various time or duration to run the process to see its affect to the recycled High Speed Steel (HSS) microstructure and hardness.

The experiment will be done a few time with different duration. Each duration will be done with a new specimen that is not treated yet. Thus, a few final output will be obtain. The output of this part of experiment is to determine the heat produced during the heating process take place.

3.5.2 Quenching Process

Next part of the experiment is where the quenching process will be followed after heat treatment process is done.

Another factor that will tested is the quenching medium which is the process to complete the hot-pressing heat treatment process. Each specimen after heated according to the required duration will be quenched using certain quenching medium. Then, the microstructure hardness data will be recorded. All quenching duration is set to 3 minutes for each quenching medium.

3.6 Analysis of Hardness and Microstructure

For this project 2 main properties that need to be check which is hardness and microstructure, so some suitable tester will be explained so that it will be used efficiently during the data collecting process is done.

3.6.1 Polishing

Before the analysis process is done, one of the pre-process that needs to be done is the polishing process. This is because before the polishing process is done, it is almost impossible to see the microstructure of the specimen due to poor surface finish of the specimen itself. In order to avoid imprecise reading of microstructure, polishing process is done prior to the microstructure analysis.

As for the hardness process, the micro-hardness test machine will be used. The machine will be using the principle of Vickers hardness test which required indentation reading on the surface of the specimen. Without polishing process, the indent area cannot be seen clearly, thus producing inaccurate reading of hardness.

This is the reason of the polishing process is done before the analysis of microstructure and hardness is done. The polishing process will be done on either one of the surface of the specimen. The hardness and microstructure reading will be taken on the surface that has already being polished. The type of polishing paper that will be used is the Silicon Carbide (SiC) sandpaper with the roughness of 300 micron, 600 micron and 800 micron

Figure 3.6: Rotating Polishing Machine (source: Google)

3.6.2 Microstructure

The next analysis for the project is the microstructure of the treated High Speed Steel. This is because microstructure is one of the element that contribute to the material properties. So before the hardness test is done, the microstructure test will be done to see what changes in the microstructure that lead to the increment of the boron steel hardness.

This analysis will also be done on each specimen that undergo different duration of heat treatment as well as different quenching medium. The data recorded will be filled in the data table above under the subchapter quenching process. From all of the data comparison will be done to determine which experiment parameters will give the most efficient and affective results to improve the recycled M2 High Speed Steel.

The equipment to perform the microstructure process is the optical microscope that is available in the faculty laboratory. The optical microscope is also known as the light microscope in the industry. This is because the microscope use the combination of light and high resolution lenses to magnify the image that is required until the microstructure of the specimen can be seen.

The optical microscope is a simple analysis tools that can be used. This is because the optical microscope have the ability to see what can't be seen by naked eye. In this project, the microstructure of the specimen is in micron. So, with the help of the optical microscope the microstructure can be seen up to 0.2 microns. The importance of the microstructure analysis in the project is to determine whether the specimen has achieve the desired material properties or not. For this project, the magnification of the microscope that has been used to see the microstructure of the specimen is 20 times. By using this level of magnification, the microstructure of the specimen can be seen. Then, the distance between the holes and line on the surface of the specimen can be calculate and analysed.

The type of microscope that is available in the lab is Zeiss optical microscope with the maximum magnification and resolution of 50 times.

3.6.3 Hardness

For the hardness of the recycled High Speed Steel, the machine that will be used is Rockwell Hardness test machine and Vickers Micro hardness tester. This tester used indenter to determine the hardness of the material tested. By using this machine we will be able to trace if there any changes in term of hardness in the material. Each specimen with different heat treatment duration and quenching medium will be tested.

Firstly, the function of the data is to see if there any effect after the heat treatment is perform on the material. Then, from all of the collected data, comparison between the data can be interpreted to determine the most efficient heat treatment duration and quenching medium.

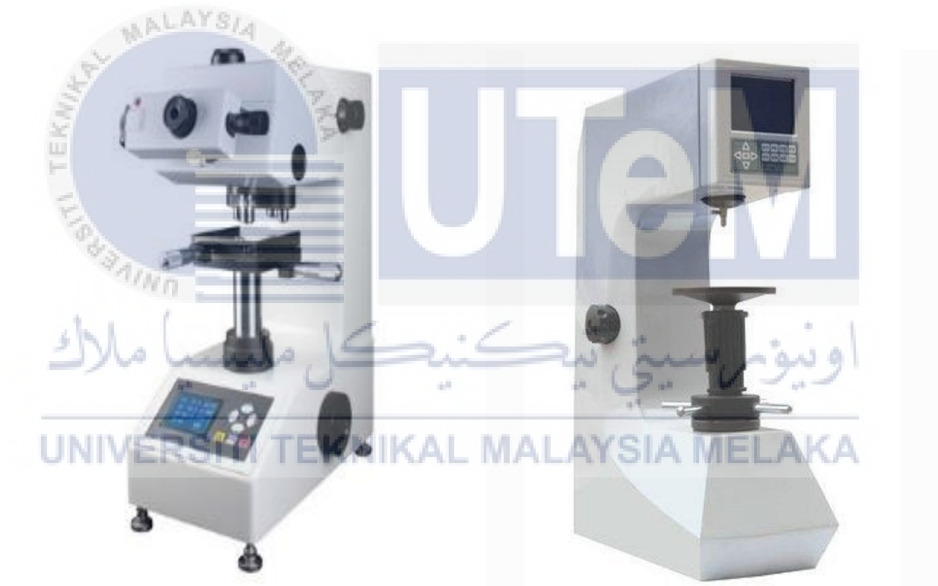


Figure 3.7: Vickers micro-hardness tester and Rockwell hardness test Machine.
(Source: Google)

3.7 Expected Results

The expected results for this project to achieve the objectives stated. Based on the methodology, we expect that most of the objectives has already been achieved by the experiment. First, we have used a resistive sintering to perform the Hot Press heat treatment process rather than using the normal machine which required a furnace. Hence, save more energy as the heating is direct and does not require longer time for preheat and large amount of electric. Then, the hardness and microstructure of the M2 High Speed Steel specimen also been tested after the heat treatment is done and the data can be obtained from this experiment. From the treated M2 High Speed Steel specimen, we know that the scrap M2 High Speed Steel can be improved. Finally, the quenching medium and its effect to hardness and microstructure also has been carried out during the experiment. The most suitable quenching medium can be determined after the experiment is done.

CHAPTER 4

RESULTS AND DISCUSSION

Introduction

In any experiment or projects, it's main focus is to obtain the results or data through the experiment conducted. In this chapter, we will focus on the discussion of the experiment output which is the temperature of the material during the heating process is done, the hardness and microstructure of the material after the process is done.

4.1 Temperature of Heating for Quenching Process

In order to increase the hardness of the material used which is recycled M2 High Speed Steel, the heating process need to be conducted. According to Nishibata & Kojima (2013), by heating the material it will reduce the strength of the material and at the same time increase its ductility. Here is where the quenching process takes place. The rapid cooling of heated material will increase the strength of the material due to martensite transformation.

The heating process will also effects changes of the microstructure of the material. According to Fan et al., (2010), microstructure refinement is the cause of the hardness to increase. However, the experiment should be conducted by using Resistive Sintering Machine. But due to the pandemic, it is hard to enter the lab to use that machine. However, with help from my supervisor, we manage to heat the material by using furnace. It will not affects the result of the experiment.

In the industry, the heat treatment is done using a furnace which means the heat transfer is through radiation. By using the resistive heat sintering machine, heat transfer can be done in direct contact as the material will be placed on the heating element itself. This will show different in term of method used.

The result of the heating process will be shown in the table below according to the temperature applied to the heating process is done.

Temperature (˚C)	Figure
600	
700	

800	

Table 4.1: Temperature and figure of the process

4.2 Hardness of Quenched M2 High Speed Steel

Next for the key performance that the project needs to investigate is the relationship of temperature of the heating process and the quenched medium for the specimens. This is to determine which parameters and variables will produce the highest hardness output. However, there are a few limitations of machines used in the heating process as the resistive sintering machine and furnace can produce a maximum temperature of 1000°C.

But in this investigation, the maximum temperature used in only 800°C, so there should be no problem for this investigation.

4.2.1 Parameter 1 (None)

The first parameter for the experiment is no heating process is done and no quenching medium is used. This is to check the original or initial properties of the material used. This is to compare it with the material that is treated with different medium.

Based on the data sheet in chapter 3, the data recorded for the original specimen is as below. The data is recorded after the process of polishing is done.

Temperature (˚C)	Cooling Medium	Hardness (HV)	Average Hardness (HV)
Room temperature	None	440	442.67
		445	
		443	

Table 4.2 : Data sheet of original hardness for the specimen.

According to the graph created from the material's hardness data, the original specimen's average hardness is 442.67. This indicates that the specimen is already at high hardness condition. Thus, after heat treatment and quenching process, the material's hardness should be increased over that of the original specimen.

4.2.2 Parameter 2 (600 °C with oil quenching medium)

Next, the quenching that will be used to quench the heated specimen is oil and the temperature used is 600˚C. The oil that is being used is 10W 40. The reason oil is selected as a quenching medium is because the ability of oil to increase the martensite of quenched material is high. According to Lenzi, Campana, Lopatriello, Mele, & Zanotti (2019), 10W 40 oil is not only suitable for quenching process but also making the process a more sustainable process rather than using other oil or chemical quenching medium.

The data of hardness for the oil quenched material is shown the data sheet below. As we can see there are increment of hardness compared to the original hardness.

Temperature (˚C)	Cooling Medium	Hardness (HV)	Average Hardness (HV)
600	Oil	540.8	542.3
		541.3	
		544.8	

Table 4.3 : Data sheet for hardness busing oil quenching medium.

4.2.3 Parameter 3 (700 °C with oil quenching medium)

After that , the quenching that will be used to quench the heated specimen is oil and the temperature used is 700˚C. The oil that is being used is 10W 40. The reason oil is selected as a quenching medium is because the ability of oil to increase the martensite of quenched material is high. According to Lenzi, Campana, Lopatriello, Mele, & Zanotti (2019), 10W 40 oil is not only suitable for quenching process but also making the process a more sustainable process rather than using other oil or chemical quenching medium.

The data of hardness for the oil quenched material is shown the data sheet below. As we can see there are increment of hardness compared to the original hardness.

Temperature (˚C)	Cooling Medium	Hardness (HV)	Average Hardness (HV)
700	Oil	740.1	739.8
		737.3	
		742.0	

Table 4.4 : Data sheet for hardness busing oil quenching medium.

4.2.4 Parameter 4 (800˚C with oil quenching medium)

After that , the quenching that will be used to quench the heated specimen is oil and the temperature used is 800˚C. The oil that is being used is 10W 40 . The reason oil is selected as a quenching medium is because the ability of oil to increase the martensite of quenched material is high. According to Lenzi, Campana, Lopatriello, Mele, & Zanotti (2019), 10W 40 oil is not only suitable for quenching process but also making the process a more sustainable process rather than using other oil or chemical quenching medium.

The data of hardness for the oil quenched material is shown the data sheet below. As we can see there are increment of hardness compared to the original hardness.

Temperature (˚C)	Cooling Medium	Hardness (HV)	Average Hardness (HV)
800	Oil	986.9	987.5
		987.5	
		988.1	

Table 4.5 : Data sheet for hardness busing oil quenching medium.

4.2.5 Comparison of best output (Hardness)

After all data is collected according to the temperature of heating process and quenching medium, the parameters that gives the best output need to be determine. This is to ensure that the parameter is suitable to be used as a process to produce a better cutting tools in the future research.

To perform the comparison, the highest hardness value by each temperature parameter is chosen. The temperature, quenching medium and hardness value will be tabulated and then a graph is drawn to determine which gives the best output.

Quenching medium	Temperature (˚C)	Hardness (HV)
None	None	442.67
Oil	600	542.3
Oil	700	739.8
Oil	800	987.5

Table 4. 6: Hardness from different temperature and quenching medium.

From the table, the material's hardness for quenching medium comes from different heating temperature. This is because the quenching medium cooling rate is affecting the hardness of the material. According to Maeno et al., (2015), the quenching medium will force the cooling effect and increase cooling rate thus increase the hardness of the material.

For the oil quenching medium, oil has proven to have a higher cooling rate compared to other quenching medium. Oil that is used in this investigation also can easily found at hardware store, which is 10W 40 type of oil.

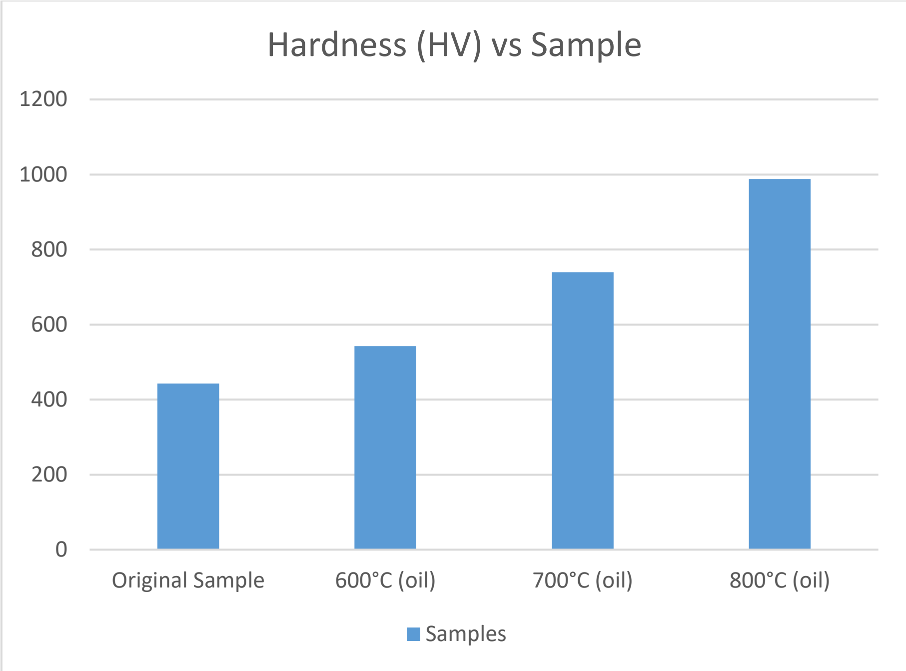


Figure 4.6 : Comparison graph of hardness in each parameter

From the graph, there a significant different of hardness value (HV) between the quenching medium. This proves that the quenching process and medium is as important as the heating process in order to increase the hardness of the material. With the influence of the quenching medium, higher hardness can be achieved.

As stated in the heating temperature of the process, the range of temperature is between 600°C to 800°C which can be consider as not a big value for this type of material, which is M2 High Speed Steel. Where its boiling point is around 1430°C. However, when the influence of the quenching medium takes place the hardness value shows a significant different between the sample.

From the graph and table, it shows that the best parameter to improve and increase the hardness of the M2 High Speed Streel is the **oil quenching medium with heating temperature is at 800°C**, which is the highest heating temperature in this experiment. So, we can say that the higher the heating temperature, the higher the hardness of the material it will be.

4.3 Microstructure of Quenched Specimen

Another main part of this project that need to be analyzed is the microstructure of the quenched material. This is because when the material has undergone heating and quenching process, the microstructure of the material will also be different from the original state. The microstructure such as martensite of the material will be altered which lead to the change of the material mechanical properties.

According to Nishibata & Kojima (2013), the increasing of the material hardness is due to the transformation of martensite during the heating and quenching process. In this analysis, the microstructure of the material will be focused on to determine which microstructure characteristics that will give the best hardness value to the specimen.

There are many types of microstructures that can be observed under the aid of the optical microscope. In this experiment, the optical microscope has been set to 20 magnification as stated in the methodology and as a result 3 main microstructure such as austenite, bainite and martensite can be observed.

4.3.1 Microstructure of Original Specimen

In order to see the difference between the original specimen microstructure and the quenched microstructure, before the heat treatment and quenching process is done the original specimen has undergo the microstructure test. The original specimen microstructure is as shown in the figure below.

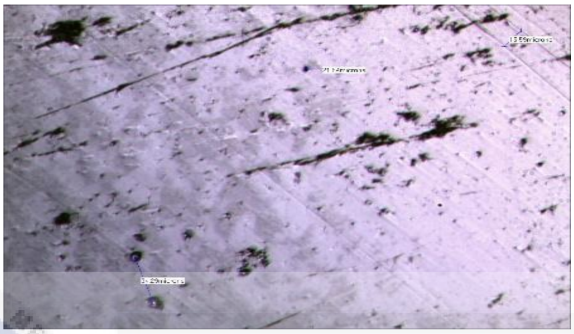


Figure 4. 7: Microstructure of original specimen under the view of optical microscope.

In the figure 4.7 shows the microstructure of the blank part or the original specimen. The surface of the original specimen shows that the part appeared with fine marks representing the original austenite condition of the part. Austenite is one of the microstructure that can be observed under the aid of the optical microscope.

According to Darvell (2018), austenite is a form of microstructure of a simple conjunction which the atoms are arranged randomly. This type of microstructure basically can be found in various metal surface. As the specimen for this experiment is M2 High Speed Steel, it is expected to discover this type of microstructure which is austenite as its original microstructure.

As the experiment continue, the heating and quenching process will be conducted on the specimen. This will change the formation of austenite microstructure. As mentioned by Limited (2012), high temperature and cooling rate are able to change the austenite into other form which is bainite and martensite. The change of microstructure and explanation will be discussed in the next subchapter.

4.3.2 Microstructure of Oil Quenched Specimen

Next, the experiment continues with another quenching medium. In this part of experiment, the quenching medium used is oil. The parameters of the experiment are different, which are 600˚C, 700˚C and 800 ˚C of heating temperature. We can see the differences of microstructure in different heating parameters.

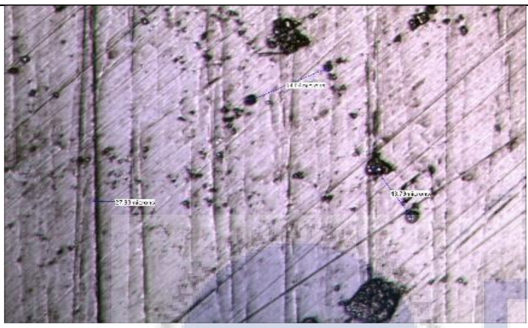
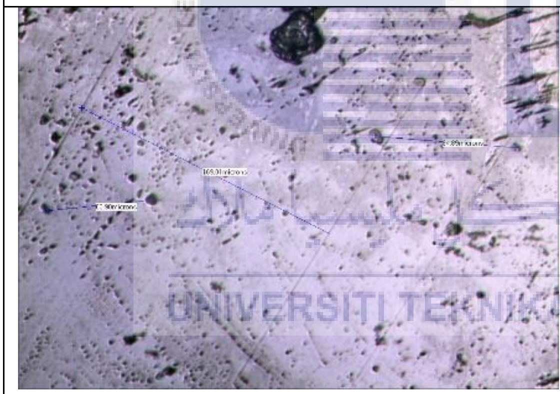
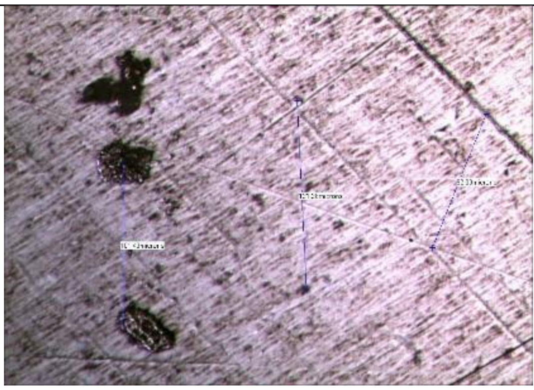
Figure	Heating temperature (˚C)
	600
	700
	800

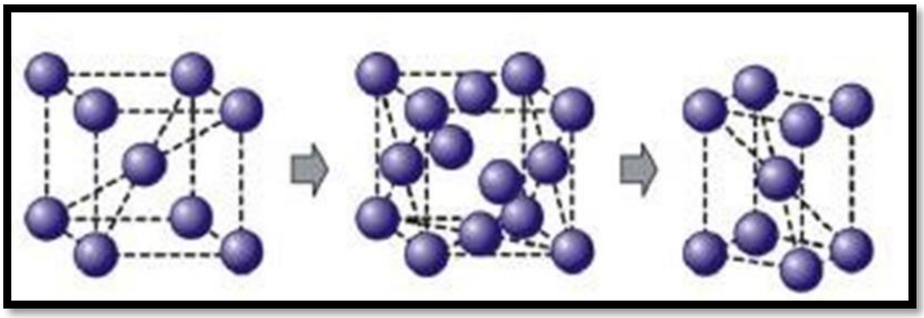
Table 4.8 : Oil quenched microstructure figure and type of microstructure with different heating temperature.

Based on the figure and table above, it shows that the microstructure that we get from the experiment, for the untreated and no quenching medium is applied specimen, the microstructure of M2 HSS appeared in a fine homogeneous grain of major ferrite phase (white colour) and minor pearlite (ferrite and cementite in dark colour). This specimen acts as an original specimen and to be compared with other treated specimen.

Next, for the second specimen with 600˚C heating temperature and oil quenching medium is applied, the microstructure of martensite (sharp edge) and partially ferrite or bainite phases are formed when oil quenched from the lower critical austenitizing region. We can say that it is improved a little bit from the original specimen where martensite structure is started to appear. With this type of microstructure, the hardness of the specimen is a little bit higher that the original one. This prove that heat treatment in this investigation is working.

For the specimen with 700˚C heating temperature and oil medium is applied, the martensite structure become more clearer than the second specimen since the heating process applied at the temperature of 700˚C. Thus, the higher the temperature of heating is applied to the specimen, more martensite microstructure will be seen.

Finally, for the last specimen with 800˚C of heating temperature and oil quenching medium is applied. We can see that it's microstructure shows clearer martensite. The highest martensite phases in this microstructure analysis are due to the 800˚C heating temperature and quenched which close to the austenite region temperature of M2 HSS which is 1129˚C. At this heating temperature it has a more homogeneous and fine-grained martensite microstructure. This is the reason why this specimen is the hardest specimen among all the specimen this investigation.



As received *Austenitized* *After queenched*

Figure 4.9: Microstructure evolution during heating and quenching process

Based on figure 4.9, dominate phase for M2 High Speed Steel before the heat treatment process is Ferrite. Ferrite possesses a basic Body-Centered Cubic (BCC) crystal structure.

As the M2 High Speed Steel temperature increased to higher level which is 600˚C, 700˚C, and 800˚C, the Ferrite microstructure changes to austenite where the crystal structure changes to Face Centered Cubic (FCC). FCC more ductile than BCC, therefore, facilitates a better forming process during heat treatment

As the temperature reduced rapidly, the martensite phase appeared with saturated carbon inside the crystal structure due to insufficient time for the carbon to form pearlite. As a result, the Face Centered Cubic austenite transforms to a highly strained Body-Centered Tetragonal (BCT).

4.4 Most suitable Hardness and Microstructure

As one of the objectives stated for this experiment which is to produce a suitable formulation of process of heat treatment for a cutting tool application by using the quenched M2 High Speed Steel. By analyzing 2 of the most important characteristics that is required for a cutting tool application which is hardness and microstructure, the decision on the temperature of heating process and quenching medium can be done. This is to ensure that the parameter chosen is the most optimum to produce a better formula of the M2 High Speed

Steel cutting tool.

In order to ease the selection of which parameters is the best to heat and quench the M2 High Speed Steel specimen, a ranking table is provided. Only the 3 highest value of hardness is chosen as hardness is the main characteristic that will affect the performance of the cutting tool.

A standard process selection method will be used to decide which parameter is the best output for this experiment and fulfil the cutting tool production objective.

Objectives	• To choose the best parameters for heating duration of the specimen. • To choose the best quenching medium for the specimen.
Constraint	• 3 highest hardness value only will be chosen from the experiment data. • Limited to the parameters conducted in this experiment only.
Requirement	• Produce a formulation for cutting tools production from the selected optimum parameters both heating temperature and quenching medium.
Free Variable	• Types of microstructure of the heated and quenched specimen.

Table 4. 9: Process selection to choose the optimum process.

From the process selection table, the constraint stated that only 3 highest hardness output will be selected for the screening process. This is to ensure that only the parameter with high hardness is chosen. As mentioned earlier, hardness is the most important characteristics for a cutting tools. This is the reason for the only 3 highest hardness will proceed to the screening process.

By selecting the 3 highest hardness, it will also fulfil the requirement of the process selection. The process selection is required to choose the optimum parameter that give the best output. Quenching process successful indicator is when the output of the quenched process as it is a hardening process. So, the optimum output of the process should be the output with the highest hardness value.

After the process selection is done, the screening process is continued to determine which of the parameter that fulfil the requirement and constraint of the process selection. In the screening process, all results and values that does not fulfil the requirement stated in the process selection will be neglected. The result of the screening process is shown below.

Parameter	Hardness Value (HV)	Quenching Medium	Temperature (˚C)	Microstructure
2	542.3	Oil	600	Partially Martensite and ferrite or bainite
3	739.8	Oil	700	Partially Martensite
4	987.5	Oil	800	Almost full Martensite

Table 4. 10: Screening table for the parameters that fulfil the constraint required for the process selection.

In the screening process, it shows that the 3 highest hardness value comes from the same type of quenching medium and different heating temperature. The type of microstructure is also different whereas the present of ferrite, bainite and martensite in the specimen that have go through the screening process can be seen.

The next process for the process selection will be the ranking process. In this stage the parameters that pass the screening process will be arranged from the highest to lowest. Then, each of the parameter characteristics will be given mark according to the characteristic effect to the final output which is the cutting tool. The table below shows the ranking process from highest to the lowest.

Parameter	Hardness Value (HV)	Quenching Medium	Heating temperature (˚C)	Microstructure
4	987.5	Oil	800	Fully Martensite
3	739.8	Oil	700	Partially Martensite
2	542.3	Oil	600	Partially Martensite and ferrite or bainite

Table 4. 11: Ranking table is produced based on the screening process.

For the mark that will be given for the ranked parameters, only important characteristic for a cutting tool will be given mark. In this process selection, the important characteristic that will affect the performance of the cutting tools is the hardness, temperature the heating process and the type of microstructure after quenching process is done.

All of the mark will be given from range 1 to 10 as 1 is considered as the lowest or does not affecting the cutting tool performance while 10 is the highest which is the characteristic that will mostly affect the performance of the cutting tools.

The mark for each characteristic stated above will be shown in the marking process below. In the table, characteristic that does not stated as the characteristic that will affect the performance of the cutting tool will not be listed. The arrangement of the marking table is the same as the ranking table for ease of understanding.

Parameter	Hardness (HV)	Heating temperature (˚C)	Type of microstructure
4	9	8	10
3	8	7	8
2	7	6	5

Table 4. 12: Marking table for the important characteristic to determine the optimum parameter in order to determine the best method for better output.

From the marking table, the marks given can be used to determine which parameter is the most suitable or giving the optimum output. The result from the marking process is the most optimum parameter for this experiment can be chosen.

- Parameter 4 = 9 + 8 + 10 = 27
- Parameter 3 = 8 + 7 + 8 = 23
- Parameter 2 = 7 + 6 + 5 = 18

In the simple calculation above from the marking process, parameter 3 has given the highest value. It shows that the output value of parameter 3 is the most optimum output compared to other parameter. In other word, parameter 4 is the most suitable parameter to improve the performance of recycled M2 High Speed Steel.

Although parameter 3 and parameter 2 is able to fulfil the constraint of the process selection, the marking process shows that both of parameter 3 and 2 is not the optimum parameter in this experiment. Then, making parameter 4 the winner for the process selection optimum parameter.

In parameter 4, the value of hardness is the highest compared to other parameter. This shows that the heating process and quenching medium is suitable for the process which lead to the high hardness of the specimen. Hardness is an important characteristic for a cutting tool as the main function of a cutting tool is to remove the unwanted part of a material in a machining process.

If the cutting tool have a low value of hardness, the possibility of the cutting tool to fail or damage is high when machining process is done. This will not only damage the material but will also harm the worker or user of the cutting tool. This is the reason of the hardness is very crucial in this experiment.

Next is the heating temperature for heating process. Based on the actual plan, resistive sintering machine will be used to heat the specimen, but due to the pandemic that hit our country, furnace heating machine is decided to be used as it not affect the output of the experiment. So, when the temperature of heating process is high, the microstructure of the specimen can be easily alter when quenching process is done. This is the effect of heating process to the specimen in this experiment.

Finally, the characteristic of the microstructure for parameter 4 which is the martensite phase is the type of microstructure that gets the highest score. Martensite is a phase of microstructure that has undergo change from the austenite phase. This phase of microstructure is an indicator that the hardness of the specimen has increased. With this type of microstructure, we can say that heat treatment in this experiment works.

As mentioned in the previous subchapter, martensite is the phase that can be achieved when the heating temperature and cooling rate is high. When both conditions happen, the carbon atom inside the material will be suppressed thus increase the hardness of the specimen. This is the reason of martensite is the best type of microstructure compared to austenite and bainite.

Martensite phase microstructure offer a good hardness for the cutting tool. Finally, as the specimen has been tempered and quenched, the low toughness which lead to brittle characteristics can be avoided. With the explanation given, it is proven that martensite is the best type of microstructure for the cutting tool.

CHAPTER 5

CONCLUSION

Introduction

In this part of the report, this project findings, results and discussions will be concluded. This chapter will highlight the significant of this study according to the objective of this project. In the next part of this chapter, the future recommendation to further the studies in this project will be proposed.

5.1 Conclusion

As a conclusion of this studies, quenching conducted to the recycled M2 High Speed Steel is done by using furnace heating machine. This is due to the restriction by the government to enter lab. However, all praises are to Allah, we manage to finish this investigation by the given due date. This is also with the supervised from my supervisor. With the furnace machine, temperature of the heating process can be done easily as the machine can be set by inserting parameter to the machine setup. With this machine, the output produced are still not affected.

As mentioned earlier, this experiment has been discovered about the hardness and the change of microstructure phase on the specimen. After the heating process is done using the furnace heating machine and quenching process is done in various type of cooling medium, the result for each heating temperature and quenching medium has given many variations.

Finally, after the results have been analyzed, the best parameter is selected by using screening process. This is to improve the recycled M2 High Speed Steel as stated earlier in this investigation.

5.2 Future Recommendation

As for the future recommendation for this experiment, the most important part of the process is the quenching medium. The reason of the quenching medium in this experiment is just a normal cooling medium and oil quenching medium as the restrictions due to Covid-19 pandemic. Our access to lab is limited. If there is no such problem, more quenching medium can be applied thus giving better results.

Addition of quenching medium is very important. This is because the quenching medium plays a large role in the cooling rate of the specimen, which led to the phase change of the specimen microstructure. Quenching medium such as nitrogen gas can be tested to see the effect of rapid cooling process.

As mentioned in the results and discussion, the faster the cooling rate of the quenching medium the better microstructure phase can be achieve due to the compaction of atom in the material. This is the reason of a better quenching medium can be tested in this experiment to produce a better specimen in term of microstructure and hardness.

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