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Experimental Investigation on the Mechanical properties of heat-treated AISI O2 tool steel for the Application of Mild steel metal Cutting Die Block Design

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This is to certify that, the thesis with title Experimental Investigate on the Mechanical properties of heat-treated AISI O2 tool steel for the Application of Mild steel metal Cutting Die Block Design is my original work and it has not been submitted for a degree in any university or institution.

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ABSTRACT

The heat treatment process can change the mechanical properties like impact toughness, wear resistance, and hardness in order to avoid tool surface chemistries change heat treatment distortion must be controlled, and a careful balance must be maintained. Producing successful tools and dies control of the heat treatment process is one of the most critical steps. Industries are highly demanding reliable tool steel metal to effectively develop or process components by machine related processes, hence producing dependable parent die material is crucial for tool die design. In this study, the material behavior of AISI O2 investigated in order to find the optimum heat treatment processing parameter for the application of die block design.

This research find the optimum hardness, impact energy and wear resistance of the selected material using heat treatment process parameter, Austenitizing temperature, tempering temperature and soaking time for tempering. 36Specimens prepared for the corresponding target test. Taguchi L9 orthogonal array design of experiment was used to conduct the experiment, and for each set test category, two specimen were taken to reduce variability occurred due to noise factors. MINITAB 2022 software used to identify the optimum set up of input factors with their corresponding levels. Main effect plot for signal to noise ratio revealed that tempering temperature and Austenizing temperature have a great influence on the responses.

According to Taguchi Grey relational analysis Austenizing temperature 805^{0}C, tempering temperature 200^{0}C, soaking time for tempering 2 hours are the optimum set up of heat treatment process parameter. Generated mechanical properties results are:- Hardness 63HRC, Toughness 8.25J and wear resistance (volume loos /Mass loos/) (2.47128mm^3/0.0189gram/) per 5 minutes, in order to be economical and a negligible difference of results there is also alternative result other than Taguchi Optimum result, which is at Austenizing temperature 790^{o}C, tempering temperature 200^{o}C and holding time of 1.5hr, 62.875HRC,8.25J and 2.47193mm^3 mass loss is acceptable.

For the case of wear resistance test, the loss calculated within 5minutes.

Results from this work will be applicable for die designer and die manufacture.

Keywords:- AISI O2, Tool die Material, Austenizing temperature, Tempering temperature, Soaking time, Hardness, Toughness and wear resistance

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LIST OF ABBREVIATIONS AND ACRONYMS

AISI	American Iron and Steel Institute
O2	Oil Quenched tool Steel
DA	Double Austenitization
SA	Single Austenitization
ASM	American Society for Metals
HRC	Rockwell Hardness scale
ASTM	American Society for Testing and Materials
HV	Vickers hardness
CNC	Computerized Numerical Control
SEM	Scanning electron microscopy
EDS	Energy-dispersive X-ray spectroscopy
VBN	Depth of notch wears
HSS	High-speed steel
HSCo	High-speed Cobalt
PC	Personal computer
OM	optical microscope
XRD	X-Ray diffraction
HT	Heat-treated
S/N	Signal to noise ratio
OA	Orthogonal Array

CHAPTER 1: INTRODUCTION

1.1 Background

AISI O2 is one of the famous tool steel metals used to design and develop die for the application of different manufacturing process. It developed using alloy of Molybdenum, Chromium and Vanadium and written as |1.2842| |90MnCrV8|. It is a tool steel metals that can be heat-treated with different temperature ranges, while an oil Austenitizing tool steel yields best characteristics of good durability, excellent wear resistance, and able to hold good cutting edges. Tool steel has working hardness up to 63-65 HRC and Austenitizing temperature 790-820oC [4].

AISI O2 is applicable for universal use like mold inserts for high hardness and abrasive stress, cold forming dies, highly stressed plastic molds, shear blades for paper, blanking and stamping tools for all types cutting sheet metals up to 6 mm thickness, deep drawing tools, woodworking tools [5]. In most case AISI O2 is exposure to impact load because this material is applicable for making of machine dies and punch.

AISI O2, as Germany specification can be written as |1.2842| |90MnCrV8|, it is a tool steel metals that can be heat-treated with different temperature [27]. AISI O2 is oil-hardening tool steel with characteristics of good durability, excellent wear /Abrasion/ resistance and it is able to hold good cutting edge, besides it does not withstand excessive heating. It has working hardness up to 63-65HRC and Austenitizing temperature 790-820oC.[4] The chemical composition result from Spector meter shown in the following Table 1.1spectrometer result for chemical compositions.

Table 1.1 Chemical composition of AISI O2 steel

C%	Si%	Mn%	Cr	Mo	Ni	V	W	P
0.941	0.891	2.50	0.190	0.0030	0.097	0.333	0.153	0.03

Table 1.2 Physical property [4]

Density	7.66x1000Kg/m3

Those who develop or process components needs reliable tool steel because tool steel is mostly used to develop/create/ cutters /die/.To get a different level of hardness, wear resistance, and toughness, tool steel are can be heat treated. The presence of cobalt and nickel as compositional elements in tool steels has high strength. On the other hand, chromium, Vanadium, and tungsten are added during alloying process and it makes tool steel have wear resistance. These properties make tool steel needed by manufacturers [45]. The heat treatment process can change the mechanical properties like impact toughness, wear resistance, and hardness in order to avoid tool surface chemistries change heat treatment distortion must be controlled, and a careful balance must be maintained. Producing successful tools and dies control of the heat treatment process is one of the most critical steps [42].

Die is a machine tool for imparting a desired shape, form or finish to a material. It known that cutting die is an impact load application machine members subjected to a sudden impact or repeated impact load caused by the instantaneous arrest of a falling mass, consequently build-up stress leading to impact failure [6] [14].

The word “die” in itself means the complete press tool in its entirety, with all the punches, Die block, Die buttons, ejectors, strippers, pads, and blocks, simply with all its components assembled, Figure 1.1. The die components are constructing from Tool steels used in a variety of press working operations that is subject to wear, example, Punch and die block.

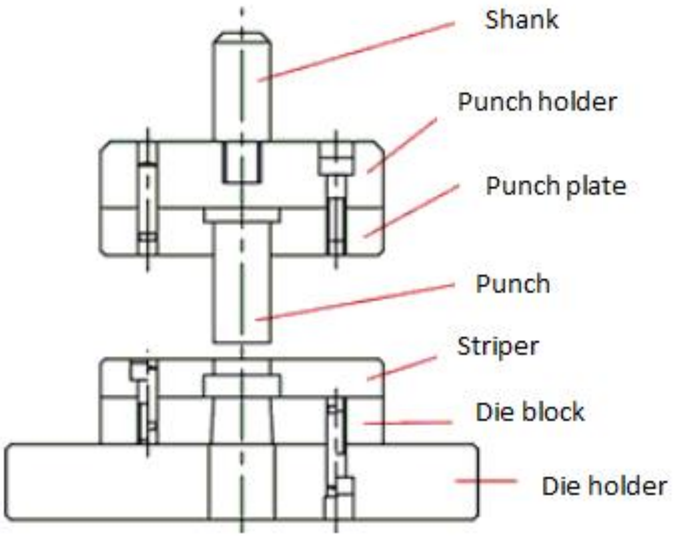

Figure: 1.1 Principle of Press Tool Die [13]

Die block is the block or plate made from high-quality steel and mounted on the bottom portion of the die set to which sections or parts of the die (the "female" part of the punch and die)[2]. The blanking die design and modeling process for sheet metal operations is quite systematic and involves various activities such as checking of part design features from manufacturability point of view, type of manufacturing operations, [2]. Die block is firmly attached to the lower die shoe. It is made of tool steel, hardened after machining.

Punch is part of die attached to the shank of the press machine, which striking the sheet metal as the main function. Tapering is a fitting type of punch and top locked by aunt. The product shape and dimension are depends on die block design [13].

Heat treatment is a way utilized to change some characteristics of metals and its alloys in order to get particular material behavior for particular kind of application. In general, the word heat treatment is the term for process employed which changes a metal or alloy steel in physical properties by either heating or cooling. Consequently, this affects the mechanical properties of the metal that has to be tested and behavioral data has recorded.

Steel heat treatment technology is a grouping of processes: heating, aging and cooling in order to alter the interior structure of a metal or alloy. In this case, the chemical composition does not change [3]. Dies fail for various reasons, including: - Abrasive wear to out-of-tolerance conditions; Heat checking and spalling/accelerated wear out; Thermal softening and subsequent deformation of dies; Excessive "benching" (hand grinding/polishing); Catastrophic failure (broken dies) and, Inaccurate dies that miss target dimensions.

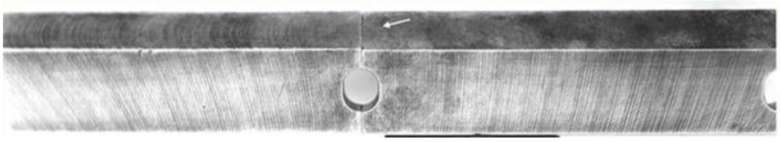

Figure 1.2 Failed Over-Austenitized A2 Rotary Knife [42]

1.2 Significance of the research

At present time, Knowing heat treatment process parameter for designed component is vital because of economical use of time, cost and delayance order for customer (to achieve the desired result) and this investigation will have also a vital role to have wide range use of tool materials.

1.3 Statement of the Problem

An accurate design of the product approach and reliable data required for manufacturing a part or product before converting raw materials to a finished product. If the design is not accurate then defects will occur in the manufactured product. The need of die block repairing originated by design and or manufacturing errors, material defects, plastic deformation and wear. The design, manufacturing and material defects pops up during the earlier part of die block life. Later, it is mainly due to plastic deformation, wear and combination of both. The combination of plastic deformation and wear leads to various surface defects, like- surface cracks, dig, scratches, broken and blunt edges.

Die manufacturers are commonly facing the problem of selecting proper system parameters, which are hardness, toughness and wear resistance while design and developing die block. Heat treatment operations different die components is also another condition to enhance and match to the design requirement. Every year, millions of dollars' worth of valuable tooling components carefully designed and machined, only sent to the heat treatment facility with little information on how to harden them. As a result, millions of production dollars are lost when parts fail prematurely due to less-than-optimum heat treatment. Designers challenged in selecting such parameters when die block design is proposed and they forcible use their intuitive decision and or trial and error approach[6], limitation of these parameter like as that of the ultimate strength and yield strength of mechanical properties of a material is mostly available in the material datasheets. However, in the engineering praxis, the designer frequently needs data on material's shear strength and hardness. Such information is very often not available, and a best estimate is needed [7]. Besides, to optimize the material behavior of a die block to be applicable for different application is mandatory. Hence selecting appropriate type and range of heat treatment for die block application is vital.

Previous studies on getting optimum hardness, optimum toughness and wear resistance after heat treatment for AISI O2 tool steel for the case of mild steel sheet metal cutting die block design are limited to the level of the author knowledge.

With the consideration of mild sheet metal application in different industries for developing different simple and complex products, parameters related with proper heat treatment types and range of operation are very important for the designer to design effective, durable and reliable die block for different industrial machines.

1.4 Objective

1.4.1 General Objective

The general objective of this research is Experimental Investigate on the Mechanical properties of heat-treated AISI O2 tool steel for the Application of Mild Steel metal Cutting Die Block Design

1.4.2 Specific Objectives

- To identify the process parameters of conventional heat treatment for selected material
- To prepare specimens for the Rockwell hardness test, impact test and wear test for the heat-treated AISI O2.
- To Investigating mechanical properties (hardness, toughness and wear resistance) of the heat-treated AISI O2 at different levels of conventional heat treatment process parameter
- To identify at which level of conventional heat treatment process parameter, mechanical properties (hardness, toughness and wear rate) will be optimum.

1.5 Scope and Limitation of the Study

This study expected to investigate the mechanical properties (toughness, hardness and wear rate), of the die material, AISI O2 tool steel with heat treatment process parameters; Austenitizing temperature, Tempering temperature and Soaking time of tempering at different three level heating temperature. The study adopts Taguchi experimental method in designing the experimental tests. The expected results only applied for a die block design for the application of mild sheet metal cutting.

1.6 Organization of the thesis document

This thesis consists of five chapters:-

This study organized with five chapters. Chapter1 discussed about an introduction and background to the thesis, which includes sub sections namely, statement of problem, general and specific objectives, and organization of the study and limitations of the study. Chapter 2 presents literature review for the study. Literatures available around this topic reviewed in way it can contribute to this works and lessons and out puts from previous works properly captured in this section. Chapter 3 focuses on experimental methods and conditions. Material, dimensions, test conditions and methods discussed in detail in this chapter. Chapter 4 deals with results from the study and discussion on research out comes. The last section, chapter 5 presents conclusions and recommendations for future work.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Tool Steels are high-quality steels made to close compositional and physical tolerances; they used to make tools for cutting, forming, or shaping a material into a part or component adapted to a definite use. The earliest tool steels were simple, plain carbon steels, but beginning in 1868, and largely early in the 20th century, many complex, highly alloyed tool steels developed. These complex alloy tool steels, which contain, relatively large amounts of tungsten, molybdenum, vanadium, and chromium, which make them possible to meet severe service demands, and to provide greater dimensional control and freedom from cracking during heat-treating [5].

2.2 Machine Tooling

Machine tooling is the process of acquiring the manufacturing components and machines needed for production.

The common categories of machine tooling includes [8]

I. Fixtures

Fixture a machine tool that is a work-griping device that grips supports and locates the work piece for a specific operation but it does not mean guide the cutting tool and used to facilitate production work in industry especially that involve in machine. The main objective of a fixture is to locate and in some cases grip a work piece during a machining operation or some other industrial process [9].

II. Jig

A work-griping device supports and locates the work piece and guides the cutting tool for a specific operation. Alternatively, it can defined, as jig is a special tool for locating and firmly holding a work piece in the proper position during a manufacturing operation [10]. Jigs are usually fitted with hardened steel bushings for guiding or other cutting tools. A jig is a type of tool used as a mechanism to control the location and or motion of another tool. A jig's primary purpose is to provide repeatability, accuracy, and interchangeability in the manufacturing of products so; it is a device that with double functions which is holding the work and guiding a tool.

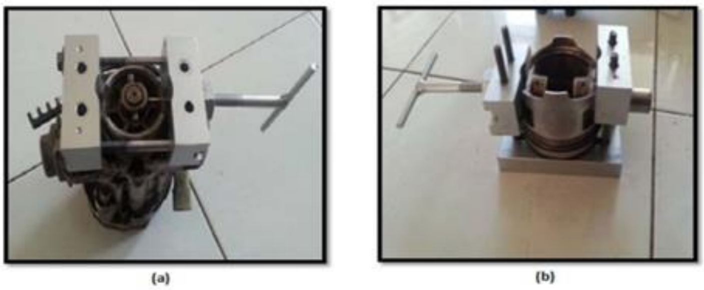

Fig. 2.1 (a) Process removal distributor pin using a jig. (b) Process removal piston pin using a jig and fixtures [43]

III. Mold

It one of machining tool that have main component of core and cavity. It is essential in manufacturing product but usually it fail or become obsolete after some period of use for a variety of reasons [11].

IV. Die

Die is also a machining tool, which is a vital manufacturing tool with the characteristics of high material utilization, low energy consumption, good product performance, high production efficiency, and low cost, which is made of high performance steels [12].

There are different types of press tool operation like piercing, forming, blanking, cutting off lancing, perforating, embossing, drawing etc. During design of die for these operations, clearance, blank holding force, punching and die radius, etc. have to be considered. Mechanical properties (permissible working stresses, impact toughness, cyclic endurance resistance to low-cycle fatigue, wear resistance and Hardness) determine the operating capacity and the life of die tools [14].

D. Statharas, J. Sideris, Medrea, and I.Chicinas deals with the fracture surfaces of a rotary cold working die that broke down during the setup process on the machine. The die was produced using AISI D2 tool steel; it designed for cutting paper at room temperature. The cutting edges, fracture surfaces and the structure, not affected by the failure, studied by optical microscopy. Historical data collected in order to check the performance of the cutting tool in relation with the cutting quality and the working time. Operating conditions, lifetime and restitution of sound operation analyzed. Samples selected and prepared for metallographic examination. The samples cut by electro-discharge, using an18 E 30 Electro jet cutting machine. Sample from the central stem and one from the fragmented area used. The condition of the cutting edges and the quality of thermal processing Studied.

Figure.2.2 Fractured Parts of the Die

As a conclusion, improvement in cutting by sharpening creates stress on the material’s surface, which decreases the die’s predicted resistance to fatigue. At time of failure analysis, two design mistakes of the cutting tool observed: - Lack of radius and hardness uniformity along the entire tool [15].

2.3 Cold work Tool Steel

Cold work tool steels grouped in high carbon steels with carbon contents of 0.7 to 1.5 percent by weight, and containing smaller amounts of chromium, manganese, molybdenum, and tungsten. They have good dimensional stability and hardenability. They further classified into three subgroups:

a. Air-Austenitizing steels
b. High-carbon, high-chromium steels
c. Oil- Austenitizing steels.

Table 2. 1. Main groups of tool steels and AISI letter symbols [5]

Group	Identifying symbol
Water hardening tool steels	W
Shock-resisting tool steels	S
Oil-hardening cold-work tool steels	O
Air-hardening, medium-alloy cold-work tool steels	A
High-carbon, high-chromium cold-work tool steels	D
Mold Steels	P
Hot-work tool steels, chromium, tungsten, and molybdenum	H
Tungsten high-speed tool steels	T
Molybdenum high-speed tool steels	M

Oil-Austenitizing cold work steels also known as group O steels consisting of O1, O2, O6, and O7 types. These steels have a high carbon content and adequate amount of alloying elements, thus achieving better hardness when oil-quenched [16].

AISI O2 steel is a tool steel of oil-hardening cold work tool steels, which means quenched with oil after heating [5].

Cold work steels are very important parts in many industries. Cold work steels required low Austenizing temperature. The range of cold work tempering is 150oC- 250oC. Grade BW and BO cold work steels are hardened at low temperature around 800 oC [17].

2.4 Properties of Mild Steel

Mild steel is a ferrous made with iron and carbon fine grain with ferrite phase structure. Its carbon content is between 0.16% - 0.29% that yields a good ductility [18]. During blanking process, it shows four different phases. The first phase is elastic deformation; it changed the shape if sufficient load applied. The deformation may elastic or plastic deformation where elastic deformation involves stretching of bonds during this phenomenon atoms do not slip past the each other. Second phase is occurs when stress is sufficient to permanently deform. Shearing deformation is a third phase fracture separation is the fourth phase and then the punch penetrate in to sheet finally will be fracture.

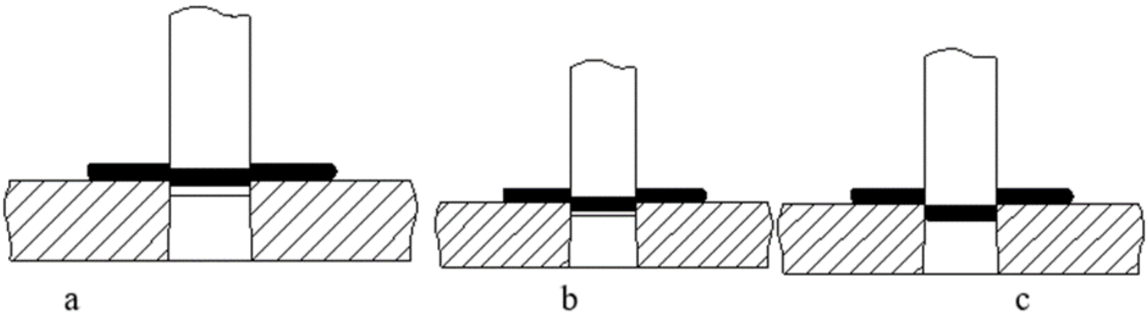

Figure 2.3 (a) Plastic deformation, (b) penetration stage and (c) Fracture stage

2.5 Heat treatment for machine tools

2.5.1 Heat treated tool Bit

Cutting tools pay a major role in manufacturing process. Wear resistance, hardness and toughness are the required important properties for long lifetime usage. Avinash D. Bagul, Dharmendra Kumar and Dubey study about the material T42 Grade. This material withstand high temperature and used for threading operation, parting and heavy turning. Nitriding process, salt bath nitro carburizing and cryogenic treatment process are the process that the author's uses for their experiment. For all heat treatment process there is an increment of hardens and conclude that the High Speed Steel (HSS) tool bit shows uniform distribution and refinement grain micro structure, so it leads the tool to more hardened [19].

2.5.2 Heat treated Mold

Polymer material that used for polymer processing has to wear resistance and corrosion resistance. To increase the corrosion resistance of the material, at least 12wt% chromium added to the steel matrix material should have selected. However, for the wear resistance and other mechanical properties, the mold material have to be heat-treat [20]. On the other hand X190CrVMo20-4 gas atomized tool steel powder material. Hot isostatic pressing (HIP) process performed at a temperature of 1150oC and at a pressure of 100MPa for four hours. Scanning electron microscope used for microstructure visualization. Aquino a 4i-Analysis software package used for determining of carbide volume fraction. After HIP and heat treatment process, for lower tempering temperature, material hardness is increased. The study result shows that heat treatment process has a pronounced effect on polymer processing materials. [20]

2.5.3 Heat treated Die

Dies are works at a typical range hardness of 58 to 680HRC [21]. Die block that have hardness of 50 to 55 HRC mostly can cut 200,000 pieces product. If the die block is hardened and tempered to 55 to 58 HRC will have a good wear resistance [22].

2.6 Heat Treatment Process Parameter

The heat treatment is a combination of a timed heating and cooling, applied to a particular metal or alloy in the solid state to produce certain desired microstructures and mechanical properties such as hardness, toughness, yield strength, tensile strength and elongation [23].

The followings are heat treatment process adopted by researcher and engineers to attain different material behavior for their component/product.

2.6.1 Austenitization Temperature

Austenitizing is the treatment where the final alloy element separating between the austenitic matrix (which will transform to marten site on quenching) and the retained carbides or austenitizing is treatment for the primary hardness. Austenitizing is the most critical of all heating operations performed on die steels excessively high. Austenitizing temperatures or long holding times may result in excessive distortion, excessive grain growth, loss of ductility and low strength. Under-heating may also result in low hardness and low wear resistance. Insufficient of heating temperature leaves ferrite that no able to transform into hard-phase [24]

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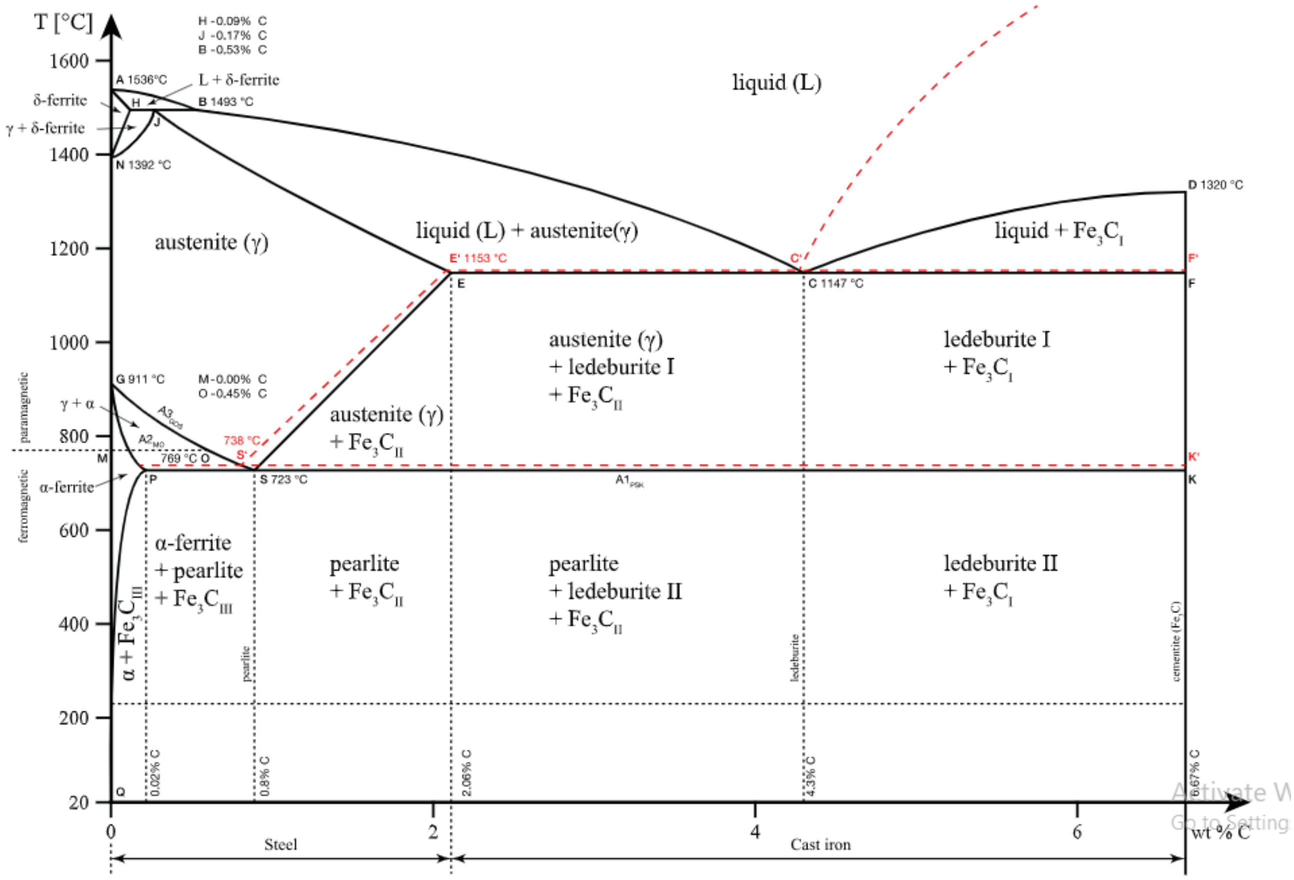

Figure 2.3 Iron-carbon phase diagram, showing the conditions under which austenite (γ) is stable in carbon steel [44]

2.6.2 Quenching Media (Cooling)

Quenching is also another important treatment to control the mechanical properties of die materials. The quenching medium must cool the work piece rapidly to get full hardness [6]. The objective of the quenching process is to cool steel from the austenitizing temperature sufficiently quickly to form the desired microstructural phases.as shown on the table2 below the researcher uses oil quench and still air as medium [5]. As of [24] one type of quenching media gives different hardness of the material than other types of quenching media.

2.6.3 Tempering Temperature

Tempering is process in which re heating of steel that earlier hardened with temperature of under the lower critical temperature, to increase toughness and ductility and to rise the grain size. Tempering modifies the properties of quench-hardened tool steels to produce a more desirable combination of strength, hardness, toughness and wear-resistance. After Austenitizing, D2 specimens of each group tempered at 160oC, 200oC, 250oC, 350oC and 550oC as show on the table 2.4 below [6]. On the other hand on the [5] the researcher did Effect of tempering temperature on the mechanical Properties of hardened 1.2842 tools steel (AISI O2) he was tempered the sample with different tempering temperature of 150,200,250,300 and 400oC.

Soaking Time

The "soaking period" is how long you keep the metal at the appropriate temperature. The purpose of the soaking stage is to keep the metal at the appropriate temperature until the desired internal structure takes shape.

I. **Austenitizing Soaking Time**

This is a length time that materials heated above their critical temperatures long enough for transformations to take place. Insufficient holding time leaves ferrite that no able to transform into hard-phase. Holding for long period give impact strength than short period of time [24]. On [6] the researcher uses Austenitizing soaking time of 30 minutes for D2 tool steel material. On [5] the researcher uses Austenitizing soaking time of 30 min for O2 material.

II. **Tempering Soaking Time**

It is a length of period that a process whereby a metal is precisely heated to below the critical temperature. On [6] the author uses 180-minute tempering soaking time for D2 material and on other hand 90 minutes tempering soaking time used for O2 tool steel material [5].

Optimization of Heat Treatment process parameter.

2.7 Related Research Works

2.7.1 Increasing Hardness

Prof. Subodh kumar uses heat treatment duration, quenching medium temperature and heat treatment temperature as parameters to study the effects of heat treatment hat by tempering after quenching the microstructure and the hardness of medium carbon steel using Taguchi method. Nine specimens prepared for the experiment. Metallographic belt surface muffle furnace, polishing machine, optical microscope, and Rockwell hardness-testing machines are the main equipment used. For their methodology L-9, orthogonal array used, which means the experiment done with nine Optimum run. On the result and discussion part, the hardness influenced by quenching medium temperature, heat treatment temperature and heat treatment duration. Out of 8500c, 9000c and 9500c, 950oC, 1hr and 300c are the optimum levels of heat-treat temperature, heat treatment duration for medium and quenching medium temperature carbon steel respectively.

Table: 2.4 Experiment layout of L9 Orthogonal Array[1]

Trail	Heat treatment temperature (℃)	Heat treatment duration(hour)	Quenching medium temperature(℃)	Hardness in RC
1	850	1	10	26
2	850	1.5	20	24
3	850	2	30	23.5
4	900	1	20	35.5
5	900	1.5	30	34
6	900	2	10	31
7	950	1	30	38.5
8	950	1.5	10	36
9	950	2	20	33

In conclusion, heat treatment temperature and heat treatment duration had a bigger effect than quenching medium temperature; it shows hardness not affected by quenching medium temperature. Heat treatment duration has a little bit effect on the hardness of the medium carbon steel materials see the table 2.4 below [1].

Table: 2.4 Experiment layout of L9 Orthogonal Array[1]

Trail	Heat treatment temperature (℃)	Heat treatment duration(hour)	Quenching medium temperature(℃)	Hardness in RC
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3	850	2	30	23.5
4	900	1	20	35.5
5	900	1.5	30	34
6	900	2	10	31
7	950	1	30	38.5
8	950	1.5	10	36
9	950	2	20	33

On the other hand, there is a research work on EN8, medium carbon steel. Three different experiment conditions, which is annealing normalizing and quenching selected. The result shows that quenching with tempering recorded highest hardness values see the Figure 2.4. As a conclusion, the authors state that heat treatment can increase the harness of steel with considerations of different condition [27].

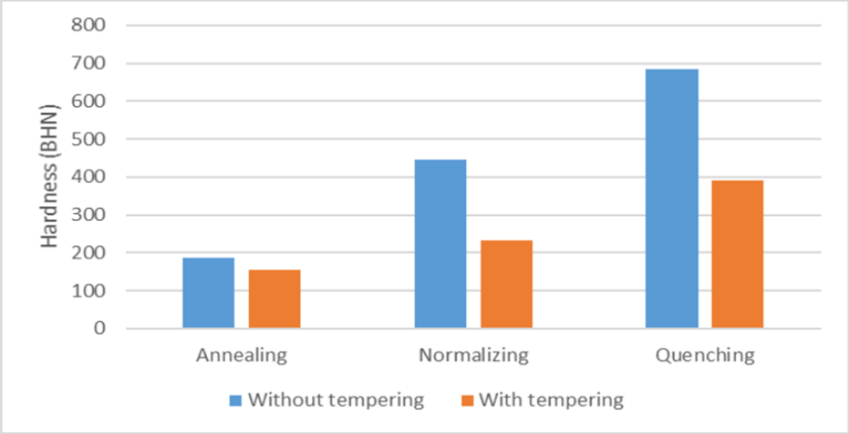

Figure 2.4 Comparison of Hardness values of EN 8 Steel for different Heat treatments [27]

The hardness of tool steel increases with austenitizing temperature increase [6]. After Austenitizing and tempering, their hardness were measured and the respective values are shown in Table 2.5[5].

2.7.2 Increasing Toughness

There is also a research work on D2 material, six D2 specimens of first group, three D2 specimens of second and third groups each and six D2 specimens of fourth group were hardened at the austenitizing temperature of 970^{o}C, 980^{o}C, 990^{o}C and 1000^{o}C respectively. After Austenitizing, hardened D2 specimens of each group tempered at 160oC, 200^{o}C, 250oC, 350^{o}C, and 550^{o}C respectively. Austenitizing soaking time of 30 minutes and tempering soaking time of 180 minutes used for D2 tool steel material [6]. After Austenitizing and tempering, their hardness and toughness measured and the respective values shown in Table 2.5 [6].

The toughness of tool steel is increase with increasing of tempering temperature. Their toughness measured and the respective values shown in Table 2.5 after Austenitizing and tempering [6].

Table 2.5 Experimental data of D2 Specimens after heat treatment [6]

Test specimens	After Austenitizing			After tempering			Objective of the experiment
	Austenitizing temperature, °C	Hardness, Rc	Toughness, Joules	Tempering Temperature , °C	Hardness, Rc	Toughness, Joules	
1st Group	970	65	1	160	65	4	To get optimal combination of hardness and toughness through changes of microstructure by heat treatment. **For the application of die**
				200	64	6	
				250	63	7	
				300	61	8	
				550	57	9	
2nd Group	980	66	1	160	66	-	
				200	65	5	
				250	64	-	
				300	62	-	
				550	55	10	
3rdGroup	990	70	1	160	69	-	
				200	67	5	
				250	65	-	
				300	64	-	
				550	54	12	
4th	100	72	1	160	71	4	
				200	69	5	
				250	67	6	
				300	65	8	
				550	53	13	

2.7.3 Increasing Wear Resistance

There are three basic stages of tool wear are - Abrasive wear it is the first stage that facilitating for the development of second stage of wear. Adhesive wear: - it is it is the second stage of wear. Fatigue wear is the third stage that leads to ultimate destruction of the tool. Cold work tools like dies and punches expose to abrasive wear so it can be improve abrasive resistance of meristic steel [29].

Steels AISI D2 and O1 with the same hardness of 60HRc their performance examined with under three modes of wear , adhesion, three-body and two-body abrasion, the wear resistance of AISI O1 and D2, is experimentally measured and assessed. The results show that for relatively slow sliding speed AISI O1 steel performs up to 12 times better than AISI D2 steel in adhesive wear, but for higher sliding speed the result is reversed [30].

Tool steels grouped with their wear resistance, high hardness and toughness. Abrasion resistance and hardens can increase by modern conventional methods. Surface Austenitizing, carburizing and nitriding grouped as traditional surface Austenitizing method and physical vapour deposition (PVD) and chemical vapour deposition (CVD) are coating process as a modern surface treatment process.

Coating material is applied in form of atomic, ionic and molecular to the surface of the component to be coated for physical vapour deposition (PVD) the process are perform at low temperature range of 50^{o}C-550^{o}C,this means the fabric structure does not modified the sub layer substrate. On the other hand chemical deposition processes are processed by suitable composition of two or more gaseous compounds are introduced within the reactor furnace and thermally reacted. The result will be product condensed on the part surface and for a solid coating. The process-taking place within the temperature range of 600^{o}C-1100^{o}C.

As a conclusion both traditional and modern processes increase the life and efficiency by increasing wear resistance of tool [31].Depending the heat treatment parameter wear resistance may vary for a given hardness. High wear resistance recommended for tool steel [28].

Researchers studies the effects of heat treatment on wear resistance. The author uses the following data 5,10 and 20N loads 150m sliding distance,200 r.p.m rotational speed for a time length of 10min.On the other hand 5,10,15 and 20 min test duration at a constant load of 10N.The author get a result that wear rate is increases when test duration and load increases[2].

Table 2.6 Optimum runs by RSM [26]

	C1	C2	C3	C4	C5	C6	C7
	StdOrder	RunOrder	PtType	Blocks	LOAD	SPEED	TRACK LENGH
1	10	8	2	1	2.5	1000	40
2	11	6	2	1	2.5	200	120
3	4	12	2	1	4.0	1000	80
4	5	7	2	1	1.0	600	40
5	7	14	2	1	1.0	600	120
6	3	3	2	1	1.0	1000	80
7	2	1	2	1	4.0	200	80
8	9	5	2	1	2.5	200	40
9	15	2	0	1	2.5	600	80
10	1	4	2	1	1.0	200	80

2.7.4 Corrosion Resistance

Now a day Steels that are used for processing synthetic materials is fast growing within the market. By using heat treatment can achieve full corrosion resistance tool. However, it is not by transformation of the feritic body center cubic (BCC) lattice structure in to face center cubic (FCC). Austenitic as usual, instead, it is by formation of a solid solution containing C and N a minimum content of 13%Cr has to dissolved and evenly distribute within the austenite. The aim of [30] paper was to investigate the increasing N solubility due to Cr content in the austenite. The author stated that corrosion resistance was depends on tempering temperature.at tempering temperature between

400oC and 550oC coating process is taking place on the work piece. As a conclusion, the researcher stated that the acceptable level of toughness and corrosion properties could keep within the range of tempering temperature of 510oC-550oC [32].

2.8 Summery for Literature Reviewed

In this section, the result of the literature reviewed summarized as follows.

Out of the common categories of machine tooling, Die is one of the important machining tools. In Die set, Die block firmly attached to the lower die shoe. It is made of tool steel, hardened after machining. In most case AISI O2 is exposure to impact load because this material is applicable for making of dies and punch. Heat treatment technology is a grouping of processes: heating, aging and cooling in order to alter the interior structure of a metal or alloy. In these processes, the chemical composition does not change.

Heat treatment can increase the hardness of steel with considerations of different condition. Selecting appropriate heat treatment condition for die block application is vital. Besides designers are challenged in selecting such conditions or parameters based on their experiences for the customized die block, however when a new type of a die block design is proposed they forcible use their intuitive decision and or trial and error approach. The hardness of tool steel increases with austenitizing temperature increase. and If the die blocks are handed and tempered to 55 to 68 HRC will have, a good wear resistance [21] [22]. The toughness of tool steel increases with increasing of tempering temperature but hardness and toughness have an inverse relation. High wear resistance recommended for tool steel [28]. Cold work tools like dies and punches expose to abrasive wear so it can be improve abrasive resistance.

In Design of experiment, Taguchi’s experimental analysis method is less expensive than response surface methodology (RSM).

2.9 Identified Gaps

From the reviewed different literatures, the following gaps are identified.

- There is no investigation on <u>open access journal</u> the optimization of hardness, toughness and wear resistance for a heat-treated AISI O2 tool steel for the application of mild steel sheet metal cutting die block design.
- Tool and die manufacturer hide the main properties that they discover for the sack of the company alive.
- Companies who produce tool steel do not show openly the material properties for specific purpose

CHAPTER 3: MATERIALS AND METHODS

3.1 Material

The base material used in this study is AISI O2 tool steel, which is one of the famous materials, used for design and manufacture cutting dies as discussed the properties in section 1. For this study, thirty six (36) specimens were prepared from parent material. AISI O2 steel, following the standard sizes respective to the targeted tests (55mmx10mmx10mm for charpy impact test and Φ6mmx12mm for wear test). After conventional heat treatment process (Austenitizing quenching and tempering), the targeted test types are hardness, toughness and wear rate, 18 specimens were dedicated for each tests. The targeted tests focused owing to the advantage of the reference material to inherent in sustaining the possible crack formation due to impact loading, stable crack propagation of the material for the designed lifetime if it attain the targeted range, moderate wear rate in operation.

The Spectrometer used to identify the chemical composition by detecting and quantifying the molecular composition using the emitted electromagnetic radiation.

3.1.1 Chemical Composition testing and testing instrument Specification

Composition test done for the material AISI O2 using spectrometer to check whether the parent material compositions match the AISI O2 or not.

The Spectrometer used to identify the chemical composition by detecting and quantifying the molecular composition using the emitted electromagnetic radiation.

3.1.1.1 Spectrometer specification

Table 3.1 Spectrometer instrument specification

No	Name of equipment	Made in	Specification	Remark
1	Oxford instruments spectrometer	Germany	Power supply/Charger:- - Input :100-250VAC - Output :-28.8VDC - 3BAR	MOD.842 Ar/CO_2

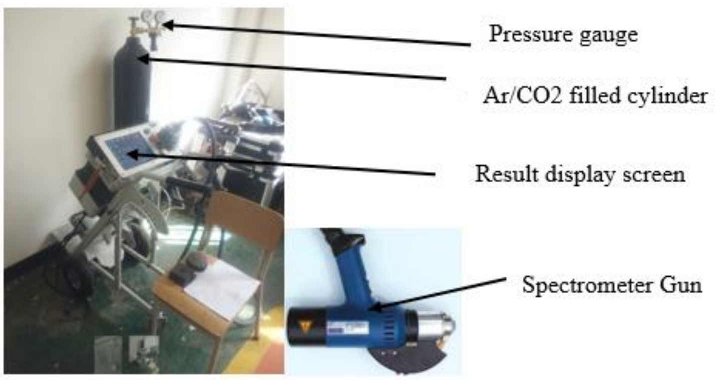

Figure 3.1Spectrometer photo

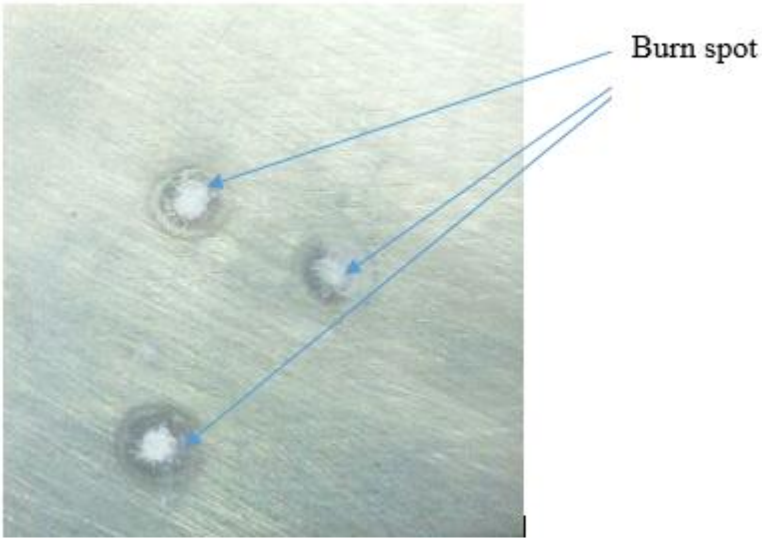

Figure 3.2 Burn spot for chemical composition test

The result of the test depicted in Table 3.2, which shows result of the parent material composition that is near to the different literature [4] [5].

Table 3.2 Chemical composition for AISI O2 steel

C%	Si%	Mn%	Cr	Mo	Ni	V	W	P
0.941	0.891	2.50	0.190	0.0030	0.097	0.333	0.153	0.03

3.1.2 Hardness Test specimen and testing instrument Specification

This test targeted to carry out with the aim of identifying the material Austenitizing level after passing the heat treatment process. The specimen prepared for impact test used also for hardness test and tested according to ASTM standard E18-22.

3.1.2.1 Furnace specification

For this investigation two types of furnaces used, which were for Austenitizing purpose, and for tempering purpose: - Fours nagat- Furnace and Lenton –Furnace respectively.

Table 3.3 Furnace specification

No	Name of equipment	Made in	Specification	Remark
1	Fours nagat- Furnace	France	1200^{o}C-Maximum Heating Temperature	Used for Austenizing purpose
2	Lenton -Furnace	England	1200^{o}C-Maximum Heating Temperature	Used for Tempering Purpose

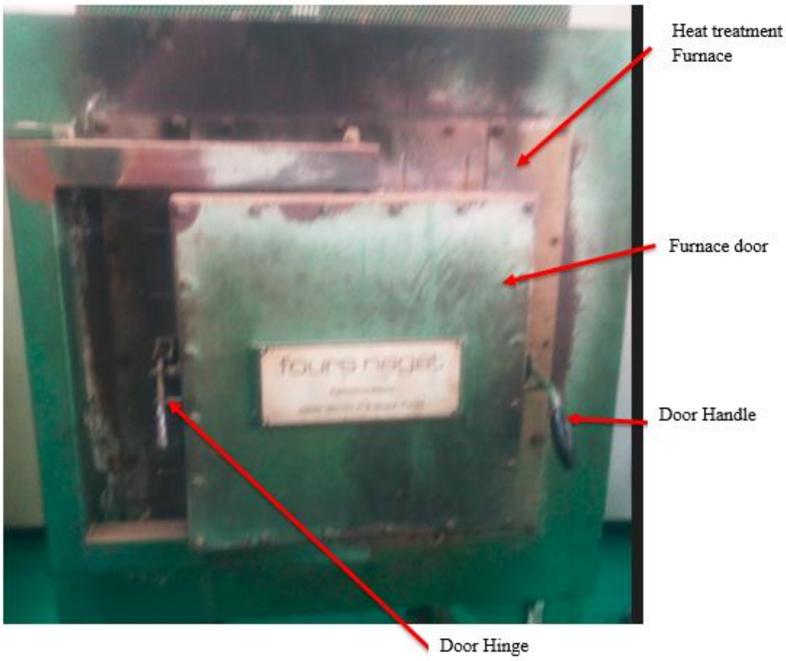

Figure 3.3 Heat treatment furnaces

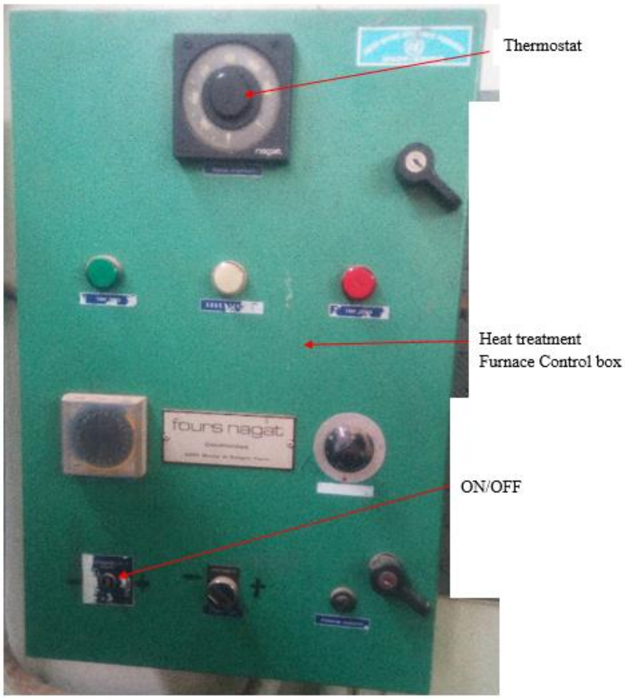

Figure 3.4 Heat treatment furnaces temperature control box

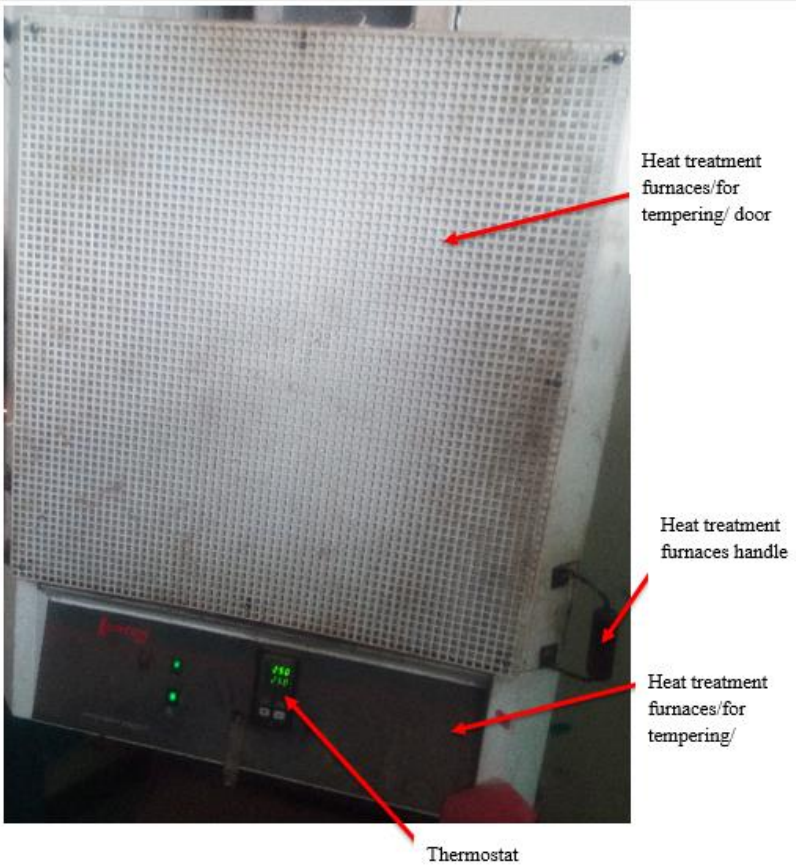

Figure 3.5 Tempering heat treatment furnace

The setup time and temperature see in the following table 3.4

Table 3.4 Time and Temperature setup

Austenizing temperature (°C)	790	805	820
Tempering temperature(°C)	150	200	250
Soaking time for Austenizing (minutes)	30	30	30
Soaking time for tempering (hours)	1	1.5	2

3.1.2.2 Agitator specification

Quenching agitator used to circulate quenching media (oil) in a quench bath through impellers, after heating the specimen.

Table 3.5 Agitator specification

No	Name of equipment	Made in	Specification	Remark
1	MEZ MOHELNICE Agitator	Czechoslovakia	930rpm,3 Phase	Used to agitate the oil, in order to avoid temperature accumulation in the quenching bath

Figure 3.6 Agitator

3.1.2.3 Hardness Tester Specification

Hardness Tester is a device used to indicate the hardness of the material by penetrating harder material with permanent deformation.

Table 3.6 Hardness Tester Specification

No	Name of equipment	Made in	Specification	Remark
1	BROOKS -Hardness tester	England	90-Maximum HRC	Used to measure the hardness of the Trial

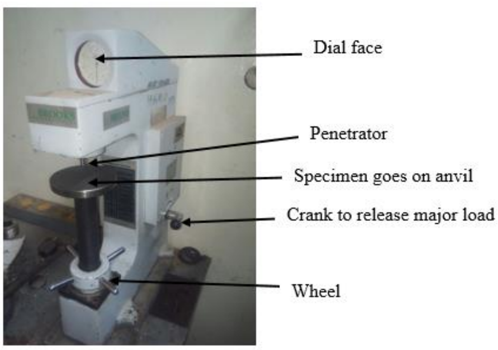

Figure 3.7Hardness Tester Specification

3.1.3 Impact test specimen and testing instrument Specification

The impact test was done with objective of identifying the toughness of the parent/ referenced material. The specimens were prepared according to ASTM A370-19, figure 3.1, for a Charpy V notch for impact test [33].

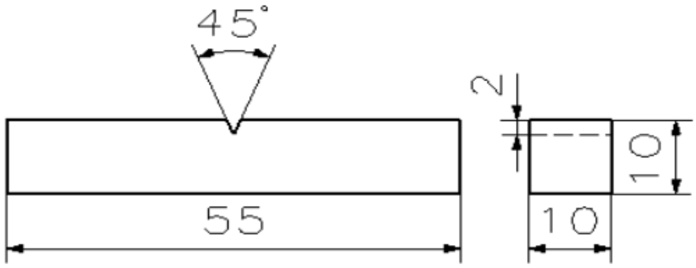

Figure 3.8 Specimen drawing for Charpy V notch impact test

3.1.3.1 Milling Machine Specification

This machine used to manufacture the impact test specimen with ASTM standard dimension of 55mmx10mmx10mm.

Table 3.7 Milling machine specification

No	Name of equipment	Made in	Specification	Remark
1	Universal Milling Machine	Italy	Total power : 9.64 KW Model : FU-3	Used to machine/manufacture/ specimen for impact test

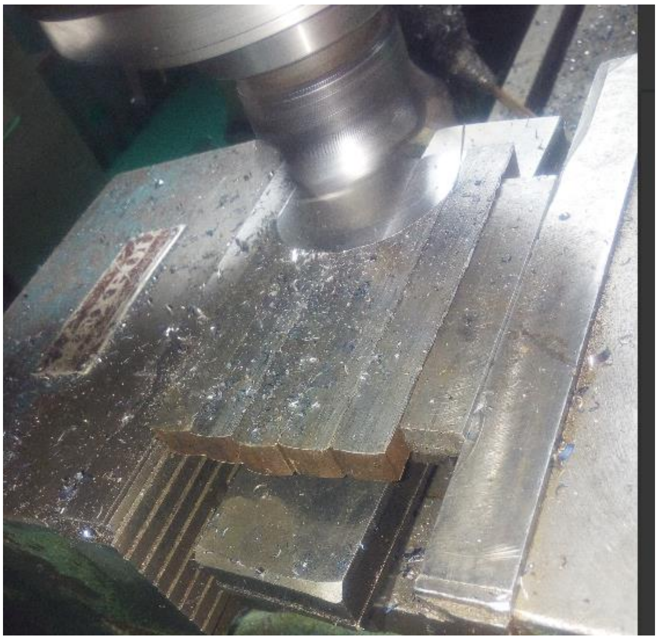

Figure 3.8- during specimen machining

Figure 3.9 checking prepared specimen dimension for impact test

3.1.3.2 Impact Tester Equipment Specification.

This machine used to measure the impact energy of the material after heat treatment.

Table 3.8Impact Tester Equipment Specification

No	Name of equipment	Made in	Specification	Remark
1	B BROOKS, Charpy Impact energy tester	England	Model. No, IT50 SER.No, 010106 Load -18kg	Used to measure impact energy

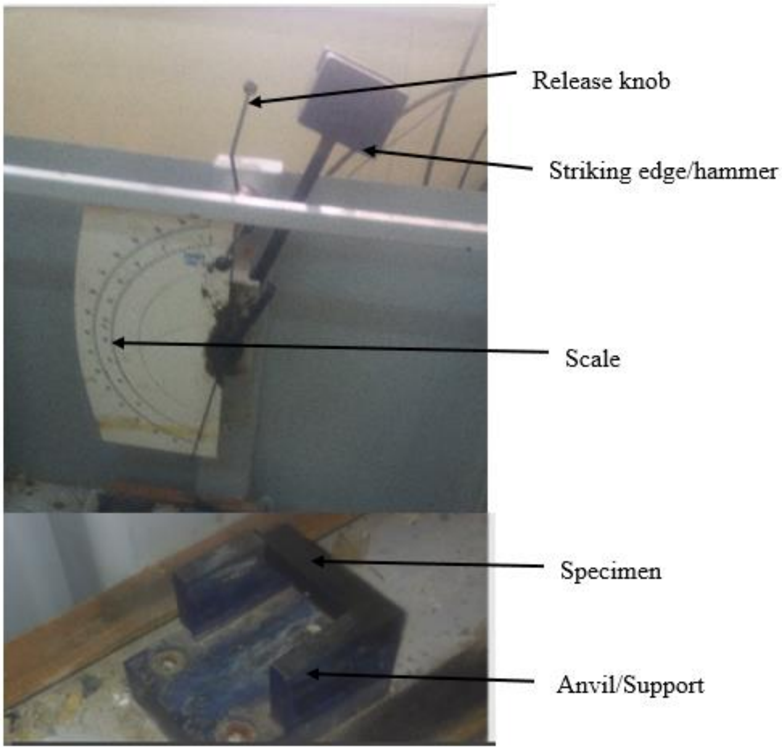

Figure 3.10 Impact tester Equipment

3.1.4 Wear test specimen and machine specification

This test was targeted to know how much material is lost within five minute and the test done according to ASTM G99, figure 3.2 shows specimens prepared to conduct the Wear rate test for the parent material [34].

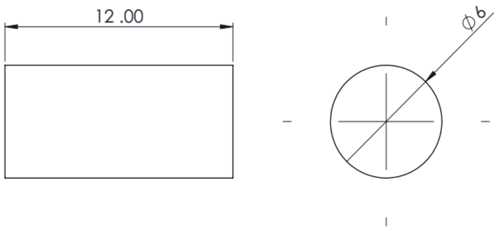

Figure 3.11 Specimen drawing for wear test

3.1.4.1 Conventional lathe machine Specification

This machine used to machined/manufactured/ wear test specimen and the machine have the following specification.

Table 3.9 Conventional lathe machine Specification

No	Name of equipment	Made in	Specification	Remark
1	Conventional lathe Machine	England	Model M460 GH, Serial 4M015/103 Spindle speed ranges from 20 to 1600rpm	Used to machine/manufacture/ specimen for wear test

Figure 3.12 conventional lathe machine

Figure 3.13 checking prepared specimen dimension for wear test

3.1.4.2 Wear tester Machine specification

Wear test done in Addis Ababa science and Technology University

Table 3.10 Wear tester machine specification

No	Name of equipment	Made in	Specification	Remark
1	MICRO PINON DISC TRIBOMETER TR-20-MICRO	USA	Power input 220V,50Hz Maximum Load,60N Minimum Load,2N	Used to mass removal

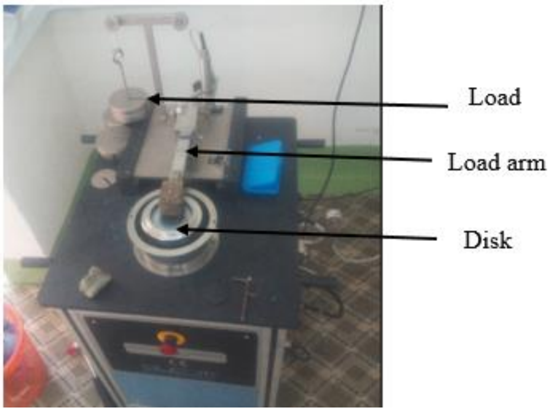

Figure 3.14 Wear tester Machine

3.1.4.3 Weight balance Specification

Using the weight balance the specimen mass measured before and after wearing the specimen on pin on disk.

The measurement done in National Metrology Institute Calibration using the following five decimal number weight balance.

Table 3.11 Weight balance Specification

No	Name of equipment	Made in	Specification	Remark
1	Sartorius weight balance	Germany	0.00000 g/Can measure up to five decimal place/	Used to measure mass of specimen for wear test

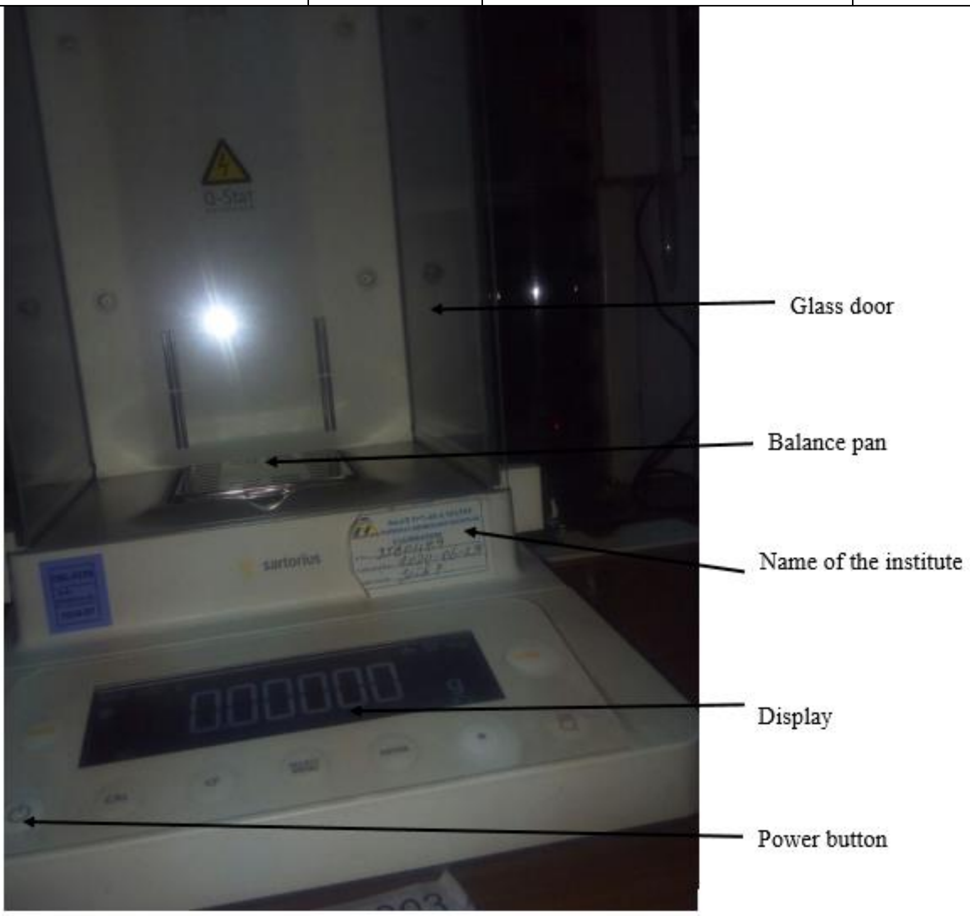

Figure 3.15 Weight balance

Experimental Procedure

According to ASTM G 99 – 95a the following procedure is follow:-

i. Clean and dry the specimen:-in order to remove dirty and foreign matter
ii. Measure the weight before and after wear in order to get the lost amount
iii. Insert the specimen in its holder
iv. Apply the load
v. Set the rpm and time length:-in order to manage the test
vi. Start the motor
vii. Remove the specimen after the desired time achieved
viii. Finally re measure the weight

3.2 Experimental Method

To arrive on the stated objectives of this study, the general process of the study outlined in flowchart of figure 3.3

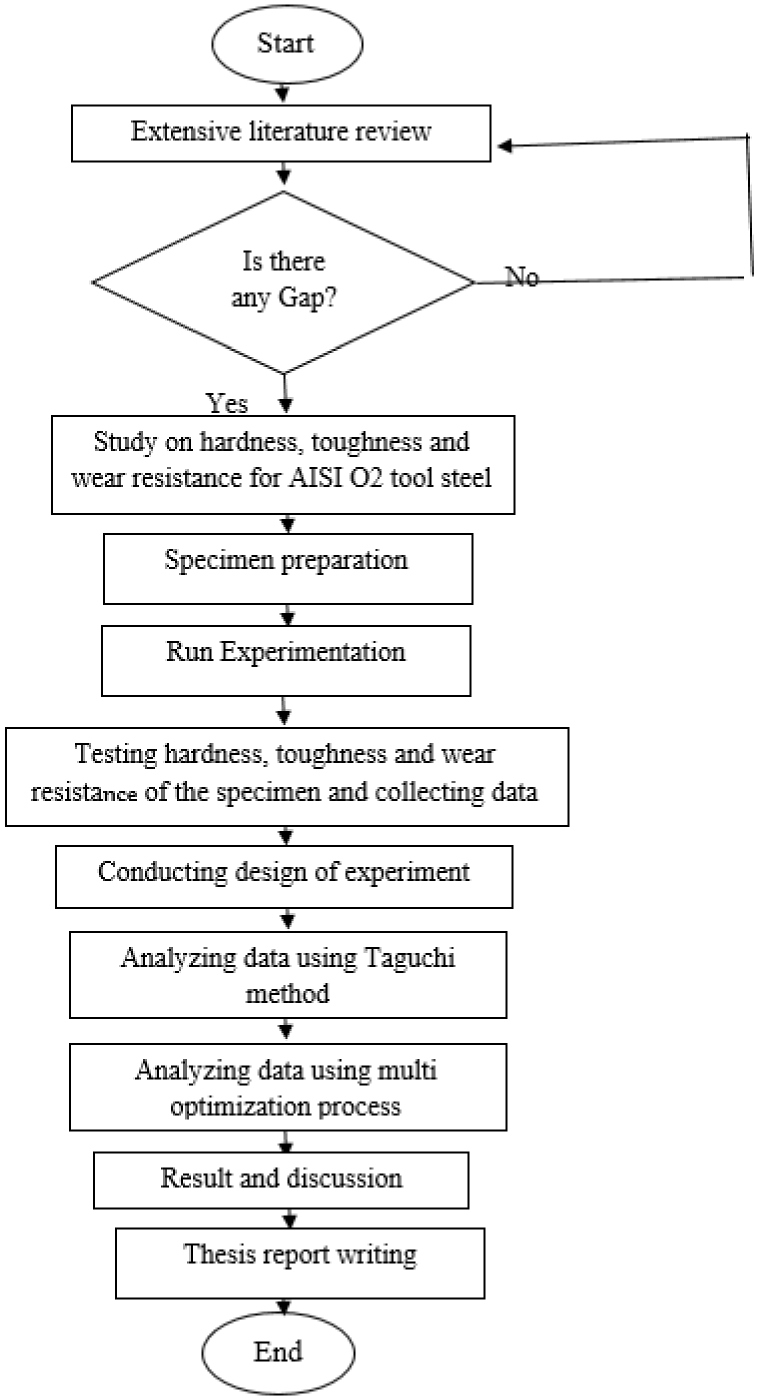

Figure 3.16 General Flow Chart of the study

3.3 Design of Experiment (DOE)

DOE can defined as a branch of applied statistics that deals with planning, conducting, analyzing, and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters. Design of experiment is the most and power full data-analyzing tool used to run the experiment with systematic planning. Analyzing the effect or response of many factors and levels with a minimum amount of experimentation [36].

3.3.1 Taguchi Method

Taguchi adopted the DOE technique. For experiment design, Taguchi created a set of tables of numbers called orthogonal arrays, used to lay out experiments of particular factor constituents. For analyses of results, Taguchi follows basic statistical calculation such as average and analysis of variance (ANOVA). Because of the advantages discussed in the literature above, the Taguchi method selected for this investigation. This method used for product optimization, which means a determination of best from control factor, the process of finding the condition that gives the maximum or minimum values of a function [36].

L_a (b^c) is Taguchi's orthogonal array symbolic representation where, L is Latin square experimental design, a number of a run (experiment), b number of levels and c is controlled factors or number of columns.

Optimization:-Minimizing the effects of noise by determination of best level of control factors called Optimization.

Factors: - is an independent variable that affects or influence the result of the system.

Levels of a factor: - The assigned values of a factor that investigated on an experiment.

Response:-It is dependent variable which is the result obtained from.

Noise factors: - are factors that do not have any controlling mechanism or it is factors, which expensive to avoid but it can be, minimize the influence.

Signal factors: - factors that changes the values of the response variable.

Signal to noise ratio: - it measure the variation of the response relative to target value within different noise condition. Taguchi to get the optimum result using this quantitative analysis.

Taguchi proposed three categories of quality characteristics as shown in the equation bellow, the larger the better (Eqn3.1), the smaller the better (Eqn3.2) and the nominal the best (Eqn3.3)

$$\text{S/N ratio} = -10 \log_{10} \left(\frac{1}{n}\right) \sum_{i=1}^{n} \frac{1}{{y_{ij}}^2} \qquad (3.1)$$

$$\text{S/N ratio} = -10 \log_{10} \left(\frac{1}{n}\right) \sum_{i=1}^{n} {y_{ij}}^2 \qquad (3.2)$$

$$\text{S/N ratio} = 10 \log_{10}\left(\frac{n-1}{n}\right) \frac{(\sum_{i=1}^{n} y_{ij})}{\sum(yi-y)^2} \qquad (3.3)$$

Where, n = number of observations

yij = observed response value where i=1, 2 ...n; j=1, 2...k [35]

Steps Involved in Taguchi Method

The steps applied for Taguchi optimizations in this study were listed follows [36].

- Identify the noise factors,
- Define the process objective,
- Determine the design parameters affecting the process,
- Create OA for the parameters design indicating the number of experiments,
- Conduct the experiments,
- analyze the data and determine optimum levels for control factors,
- Perform the verification experiment.

To identify the contribution the input parameters and the interaction between the output parameters, Analysis of Variance (ANOVA) was used [37].

Control factors	**Noise factors**
Austenitizing temperature (^oC)	Furnace condition
Tempering temperature (^oC)	Operator skill
Soaking (Holding) time for tempering (hours)	Machine condition and vibration

Table 3.12 Factors that affect heat treatment process

3.3.1.1 Identification of the Objective Function

Objective function: Larger the better for hardness and toughness (Eqn. 3.1) and the smaller the better for wear (Eqn. 3.2).

3.3.1.2 Identification of Control Factors and their Levels

Table 3.13 Selected Factors and their Levels

Factor	Level		
	Low	Medium	High
Austenitizing temperature (^oC), 30 min per each	A1=790	A2=805	A3=820
Tempering temperature (^oC)	B1=150	B2=200	B3=250
Soaking (Holding) time for tempering (hours)	C1=1	C2=1.5	C3=2

3.3.1.3 Selection of Orthogonal Array

Degrees of freedom (DoF), provides an indication of the amount of information contained in a data set. DoF applied to characterize three separate items as follows.

- DoF of a factor = No of levels of the factor - 1
- DoF Austenitizing Temperature = 3 - 1 = 2;
- DoF Tempering temperature = 3 - 1 = 2;
- DoF Soaking Time for Tempering Temperature = 3 - 1 = 2
- DoF of an experiment = Total no of experiments – 1
- DoF of an experiment =9- 1 = 8.

The DoF for the error will be equal to the actual degrees of freedom for the study minus the sum of the degrees of freedom for the various factors.

DoF Error = Total DoF - Sum of each parameter = 8 – (2+2+2) = 8 – 6 = 2

Table 3.14 L9 Orthogonal Array (OA) of Taguchi

Number of Run	Austenitizing Temperature (^oC)	Tempering Temperature (^oC)	Soaking (Holding) Time for Tempering (Hours)
1	Low	Low	Low
2	Low	Medium	Medium
3	Low	High	High
4	Medium	Low	Medium
5	Medium	Medium	High
6	Medium	High	Low
7	High	Low	High
8	High	Medium	Low
9	High	High	Medium

Table 3.15 Orthogonal Array (OA) L9

Number of Run	Austenitizing Temperature (°C)	Tempering Temperature (°C)	Soaking (Holding) Time for Tempering (Hours)
1	790	150	1
2	790	200	1.5
3	790	250	2
4	805	150	1.5
5	805	200	2
6	805	250	1
7	820	150	2
8	820	200	1
9	820	250	1.5

As discussed in the literature review, the following data selected for wear rate test [2].

Table 3.16 Wear resistance testing Data

No	Load	Speed	Distance	Time
1	20N	200 r.p.m	30mm from center	5 minute

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Experimental Test Results

4.1.1 Hardness Test Results

The hardness test results of the trial 1 and Trial 2 using a total of 18 specimens and the MEAN of Hardness(HRC) and signal to noise ratio (S/N) are presented in the table 4.1

Table 4.1 Hardness test results for the trials with their calculated S/N and MEAN results

Number of Run	Austenitizing Temperature (^oC)	Tempering Temperature (^oC)	Soaking (Holding) Time for Tempering (Hours)	Hardness/HRC?		MEAN of Hardness /HRC/	Signal to noise ratio /S/N/
				Group /Trial/1	Group /Trial/2		
1	790	150	1	64.00	65.00	64.500	36.1904
2	790	200	1.5	63.25	62.50	62.875	35.9691
3	790	250	2	61.67	59.00	60.335	35.6050
4	805	150	1.5	66.75	64.75	65.750	36.3549
5	805	200	2	63.50	62.50	63.000	35.9860
6	805	250	1	62.50	61.50	62.000	35.8470
7	820	150	2	65.50	64.50	65.000	36.2575
8	820	200	1	64.25	64.00	64.125	36.1405
9	820	250	1.5	60.50	59.75	60.125	35.5806

As show in the Table 4.1, the maximum MEAN hardness is 65.75 HRC at combinations of 805^oC, 150 ^oC and 1.5 hour. The minimum MEAN hardness 60.125HRC recorded at a combination of 820^oC, 250^oC and 1.5 hours. Generally, it shows that for constant Austenitizing temperature and by differing, the tempering temperature and soaking time of tempering the result of hardness varies.

4.2 Main Effect Plots

Main effect plot tell us at which combination the result is optimum. The main effect plot uses signal to noise ratio data and confirmed by plot of MEAN.

4.2.1 Main Effect Plot for Hardness S/N Ratio

As shown in the Figure 4.1, main effect plot for S/N ratio are higher at Austenitizing temperature, Tempering temperature and Soaking time for tempering of 805^oC,150^oC and 1 hour respectively, by considering the larger result yields a better results among all.

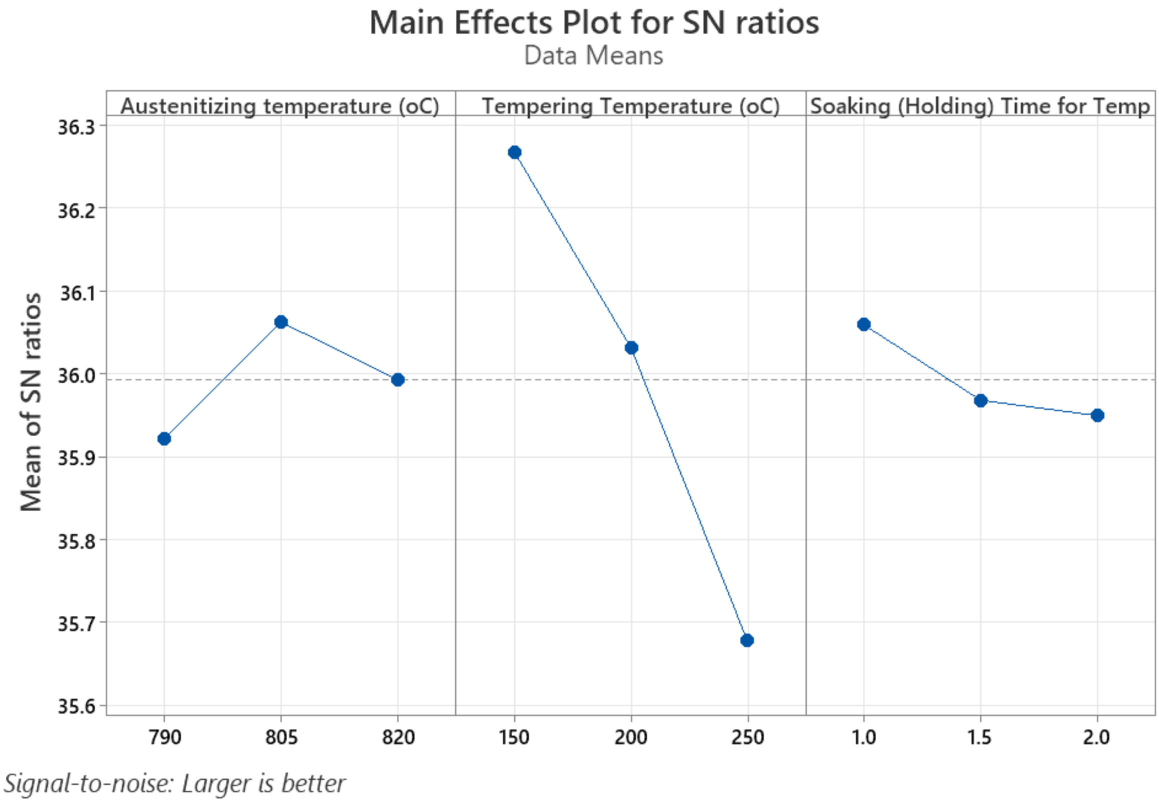

Figure 4.1 Main effect plot for S/N ratio for hardness

The S/N ratio of hardness was identified to be the minimum at Austenitizing temperature, tempering temperature and soaking time for tempering of 790oC, 250oC and 2 hour respectively. The objective was getting of maximum response for hardness, so, based on main effect plot for S/N ratio, the selected optimum combinations were 805oC, 150oC and 1 hour which reflect the Austenitizing temperature, Tempering temperature and Soaking time for tempering of ,respectively. However, such kinds of combination setup were not considered in the orthogonal array Table 4.1. This suggests a new experiment for confirmation test was required. However, this setup was only for hardness, so a single setup was required to get three of optimum results (hardness, impact energy and wear resistance). For the single die block, a single setup heat treatment process as shown in the Table 4.2.

Table 4.2 Optimum combination of input parameters for hardness response only

Austenitizing temperature	Tempering temperature	Soaking time for tempering
805°C,	150°C	1hour

Table 4.3 illustrates the rank of each the parameter /control factors effect on hardness using the extracted Delta. From the Table, It can been seen that the influence rank of each factor on the hardness response, and it can be interpreted as the effect of tempering temperature on the hardness takes the first rank, whereas Austenitizing temperature and soaking (holding) time for tempering takes the second and third rank respectively. Table 4.3 constructed by taking the average signal to

noise ratio of at each level and the delta the difference between the maximum and the minimum within the respective factors.

Table 4.3 Response table for Signal to Noise Ratio Larger is better

Level	Austenitizing Temperature	Tempering Temperature	Soaking (Holding) Time for Tempering
1	35.92	36.27	36.06
2	36.06	36.03	35.97
3	35.99	35.68	35.95
Delta	0.14	0.59	0.11
Rank	2	1	3

4.2.2 Main Effect Plot for Hardness Means

Main effect plot for Means is a plot that describes average Rockwell hardness value based on the average response value of trial one (Trial 1) and trial two (Trial 2) from the experiment. Main effect plot for Means also confirms the result of signal to noise ratios and predict the optimum process parameter.

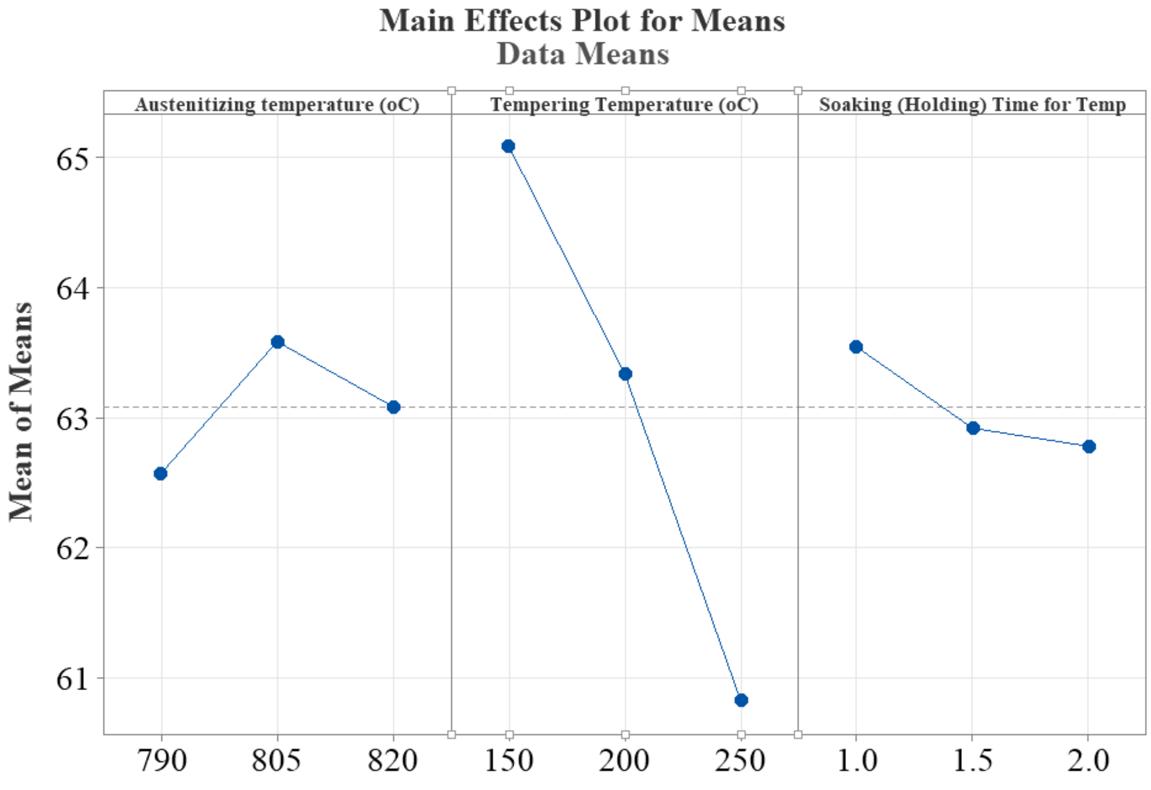

Figure 4.2 Main effect plot for hardness means

Been relies on main effect plot for hardness means, Table 4.4 generated. Table 4.4. Shows tempering significant effect on the hardness as compared to Austenitizing temperature and soaking time for tempering.

Table 4.4 Response table for hardness means

Level	Austenitizing Temperature	Tempering Temperature	Soaking (Holding) Time for Tempering
1	62.57	65.08	63.54
2	63.58	63.33	62.92
3	63.08	60.82	62.78
Delta	1.01	4.26	0.76
Rank	2	1	3

4.3 Interaction plot Analysis for Hardness Signal to Noise Ratio

Figure 4.3 shows the effects of Austenitizing temperature, tempering temperature and soaking time for tempering on hardness interaction rely on all tests using MINITAB 2022 to study the interaction these parameters. As it can be seen from the Figure 4.3, three quarter which depicts the interactions. The left side quarter describe the effect of tempering temperature and Austenitizing temperature on hardness while the right side upper quarter describe the effects of soaking time and Austenizing temperatures on hardness and the right side lower quarter describes the effects of tempering temperature and soaking time for tempering on hardness. The identified results of interactions as follow:-

4.3.1 Interaction Plot Analysis of Austenitizing temperature and soaking (holding) time for tempering on the Hardness

- ❖ Hardness is minimum at a soaking time of 1.5 hour and Austenitizing temperature of 820^{o}C and hardness is maximum at a soaking time of 1.5 with Austenitizing temperature 805^{o}C.
- ❖ For Austenitizing temperature of 820^{o}C, the hardness is maximum, medium and minimum at soaking time of 2 hour, 1hour and 1.5 hour respectively.
- ❖ For the Austenitizing temperature is 805oC, the hardness is maximum, medium and minimum at a soaking time of 1.5 hour, 2 hour and 1 hour respectively.
- ❖ For Austenitizing temperature is at 790oC, hardness is maximum, medium and minimum at a soaking time of 1hour, 1.5 hour and 2 hour respectively.

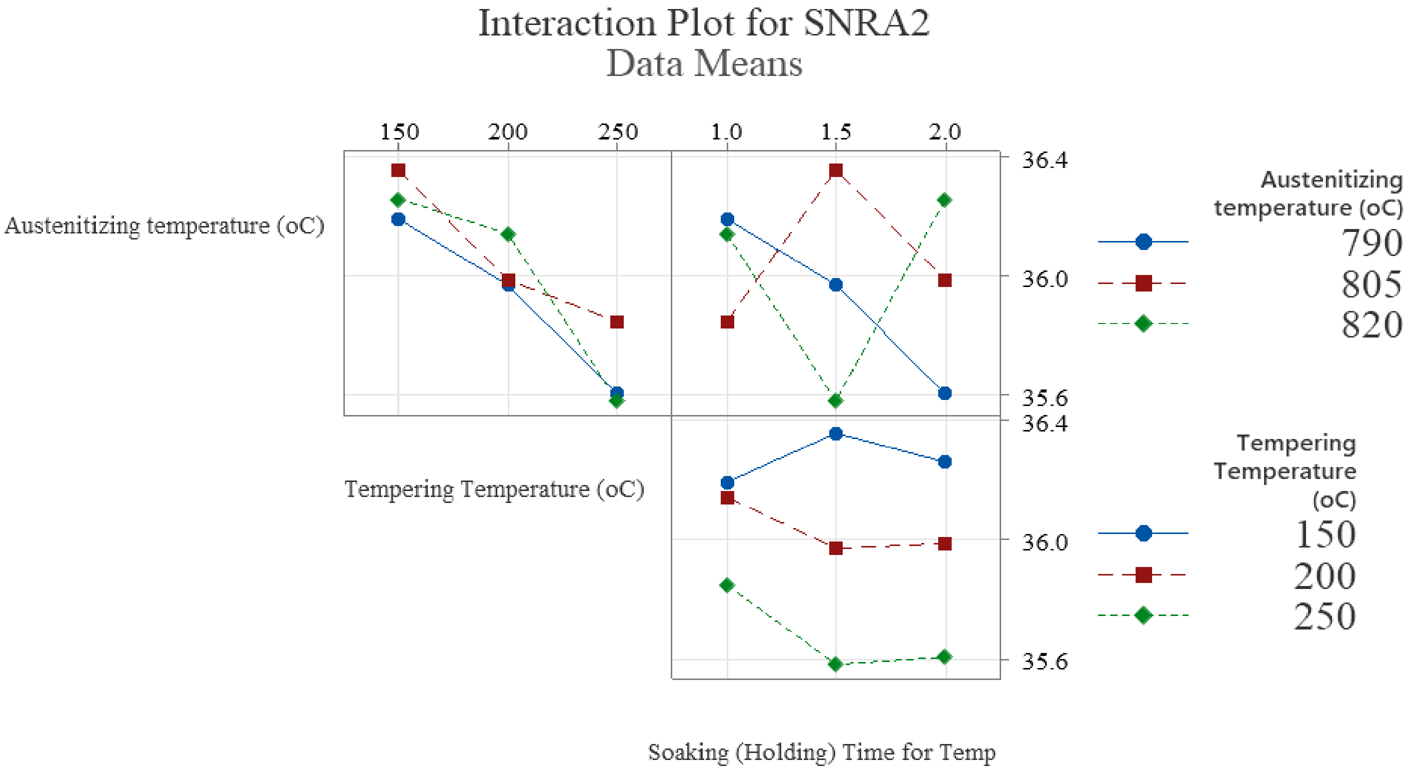

Figure 4.3 Interaction plot analysis for Means on the hardness

4.3.2 Interaction Plot Analysis of Tempering temperature and Soaking (holding) Time for Tempering on the Hardness

- For tempering temperature of 150 ºC, the hardness is maximum, medium and minimum at soaking (holding) time of 1.5 hour, 2 hour and 1 hour respectively.
- For tempering temperature 200 ºC, the hardness is maximum, medium and minimum at soaking (holding) time of 1 hour, 2 hour and 1.5 hour respectively.
- For tempering temperature of 250 ºC, the hardness is maximum, medium and minimum at soaking (holding) time of 1 hour, 2 hour and 1.5 hour respectively.

4.3.3 Interaction Plot Analysis of Austenitizing Temperature and Tempering Temperature on the Hardness

- For tempering temperature of 150 ºC, the hardness is maximum, medium and minimum at Austenitizing temperature of 805 ºC, 820 ºC and 790 ºC respectively.
- For tempering temperature 200 ºC, the hardness is maximum, medium and minimum at the Austenitizing temperature of 820 ºC, 805 ºC and 790 ºC respectively.
- For tempering temperature 250 ºC, the hardness is maximum, medium and minimum ate the Austenitizing temperature of 805 ºC, 790 ºC and 820 ºC respectively.

4.4 Contour Plot of Austenitizing Temperature versus Tempering temperature for Hardness

Contour plot figure 4.4 shows, the hardness result within the given range of Austenizing temperature and tempering temperature. The Rockwell hardness is above 65HRC within the range of 150 ^oC - 171 ^oC tempering temperature and at the Austenitizing temperature range of 794 ^oC-820^oC. HRC is minimum or below 61, at tempering temperature 237.9 ^oC – 250 ^oC with the corresponding Austenitizing temperature of ranging from 790 ^oC to 793 ^oC.

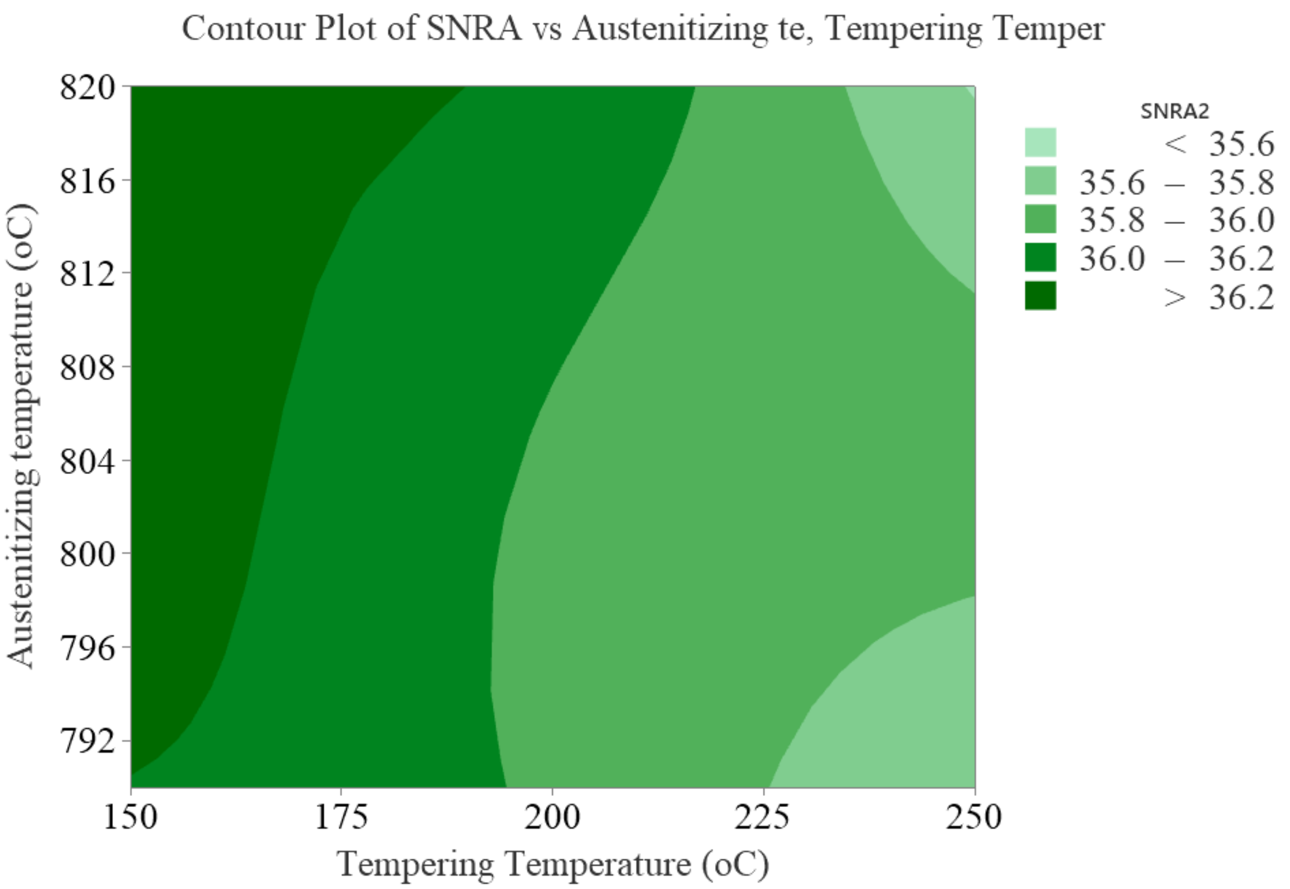

Figure 4.4 Influence of Austenitizing temperature versus tempering temperature on the mean values of Rockwell hardness

4.5 Impact Toughness (Impact Energy) Test Result

Impact energy of the material test results and calculated values of S/N ratio and MEAN registered in the following table 4.5 for trials from nine number of experiment.

Table 4.5 Impact toughness test results for the trials with their calculated S/N and MEAN results

Number of Run	Austenitizing Temperature (°C)	Tempering Temperature (°C)	Soaking (Holding) Time for Tempering (Hours)	Impact Energy /J/		MEAN of Impact Energy /J/	Signal to noise ratio /S/N/
				Group 1	Group 2		
1	790	150	1	10.0	12.0	11.00	20.7200
2	790	200	1.5	8.5	8.0	8.25	18.3171
3	790	250	2	9.0	8.5	8.75	18.8295
4	805	150	1.5	7.0	10.0	8.50	18.1804
5	805	200	2	9.0	7.5	8.25	18.2213
6	805	250	1	12.5	8.5	10.50	19.9480
7	820	150	2	7.5	7.0	7.25	17.1913
8	820	200	1	7.5	6.5	7.00	16.8354
9	820	250	1.5	8.0	8.5	8.25	18.3171

The MEAN values of Impact toughness is higher at the experiment combinations of, Austenitizing temperature 790 °C, tempering temperature 150 °C and soaking time for tempering 1hour with corresponding MEAN values of 11J. The Impact toughness is lower at the combinations of Austenitizing temperature 820 °C, tempering temperature 200 °C and soaking time for tempering 1hour with corresponding MEAN values of 7J.

The variation in Austenitizing temperature affects the impact toughness significantly as shown in the Table 4.6. Table 4.6 illustrates the rank of each the parameter /control factors effect on impact toughness using the extracted Delta. From the Table 4.6 , It can been seen that the influence rank of each factor on the impact toughness response, and it can be interpreted as the effect of Austenitizing temperature on the hardness takes the first rank, whereas Tempering temperature and soaking (holding) time for tempering takes the second and third rank respectively. Table 4.6 constructed by taking the average signal to noise ratio of at each level and the delta the difference between the maximum and the minimum within the respective factors.

Table 4. 6 Response Table for toughness Signal to Noise Ratios for larger is better

Level	Austenitizing Temperature	Tempering Temperature	Soaking (Holding) Time for Tempering
1	19.29	18.70	19.17
2	18.78	17.79	18.27
3	17.45	19.03	18.08
Delta	1.84	1.24	1.09
Rank	1	2	3

4.6 Main effect plot

Main effect plot tell us at which combination the result is optimum. The main effect plot is uses signal to noise ratio data and confirmed by plot of MEAN.

4.6.1 Main Effect Plot for Signal to Noise Ratio of Impact Toughness

As shown in the Figure 4.5 , main effect plot for S/N ratio are higher at Austenitizing temperature, Tempering temperature and Soaking time for tempering of 790ºC,250ºC and 1 hour respectively, by considering the larger result yields a better results among all.

Figure 4.5 Main effect plot for impact toughness S/N ratio

The S/N ratio of impact energy was identified to be the minimum at Austenitizing temperature, tempering temperature and soaking time for tempering of 820ºC, 200ºC and 2 hour respectively. The objective was getting of maximum response for impact toughness, so, based on main effect plot for S/N ratio the optimum combinations are selected as Austenitizing temperature, Tempering temperature and Soaking time for tempering of 790ºC, 250ºC and 1 hour respectively.

Table 4.7 Optimum combination of input parameters for impact toughness response

Austenitizing temperature	Tempering temperature	Soaking time for tempering
790ºC,	250ºC	1hour

Table 4.8 illustrates the rank of each control factors effect on impact toughness using the extracted delta. It can been seen that the influence rank of each factor on the impact toughness response, and it can be interpreted as the effect of Austenitizing temperature on the impact toughness takes the first rank, whereas tempering temperature and soaking (holding) time for tempering takes the second and third rank respectively. Table 4.8 constructed by taking the average signal to noise ratio of at each level and the delta the difference between the maximum and the minimum within the respective factors.

Table 4. 8 Response Table for impact toughness Signal to Noise Ratios for larger is better

Level	Austenitizing Temperature	Tempering Temperature	Soaking (Holding) Time for Tempering
1	19.29	18.70	19.17
2	18.78	17.79	18.27
3	17.45	19.03	18.08
Delta	1.84	1.24	1.09
Rank	1	2	3

4.6.2 Main Effect Plot for Impact Toughness Means

Main effect plot for Means is a plot that describes average impact toughness value based on the average response value of trial one (Trial 1) and trial two (Trial 2) from the experiment. Main effect plot for Means also confirms the result of signal to noise ratios and predict the same optimum process parameter as that of S/N ratio.

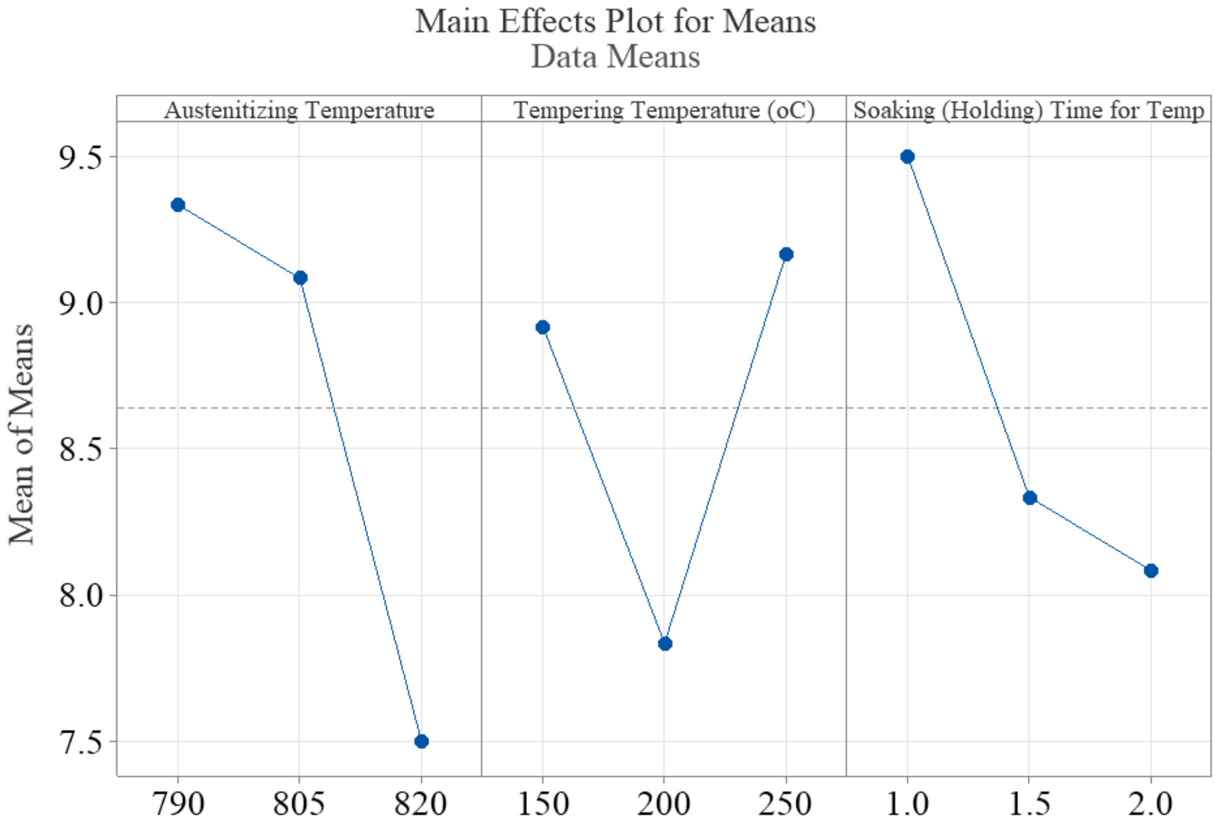

Figure 4.6 Main effect plot for Mean results of impact toughness

The figure 4.6 above shows that the optimum setup of heat treatment process parameter for impact toughness MEAN and ,so ,that higher at Austenitizing temperature, Tempering temperature and Soaking time for tempering of 790ºC,250ºC and 1 hour respectively.

Table 4.9 Response table for impact toughness mean

Level	Austenitizing Temperature	Tempering Temperature	Soaking (Holding) Time for Tempering
1	9.333	8.917	9.500
2	9.083	7.833	8.333
3	7.500	9.167	8.083
Delta	1.833	1.333	1.417
Rank	1	3	2

Depending on mean results listed in Table 4.9, it can be seen that the effect of Austenitizing temperature is higher as compared to tempering temperature-soaking time for tempering.

4.7 Interaction plot Analysis for Impact toughness Signal to Noise Ratio

Figure 4.7 shows the effects of Austenitizing temperature, tempering temperature and soaking time for tempering on impact toughness interaction rely on all tests using MINITAB 2022 to study the interaction these parameters. As it can be seen from the Figure 4.7, three quarter which depicts the interactions. The left side quarter describe the effect of tempering temperature and Austenitizing temperature on impact toughness while the right side upper quarter describe the effects of soaking time and Austenizing temperatures on impact toughness and the right side lower quarter describes the effects of tempering temperature and soaking time for tempering on impact toughness. The identified results of interactions as follow:-

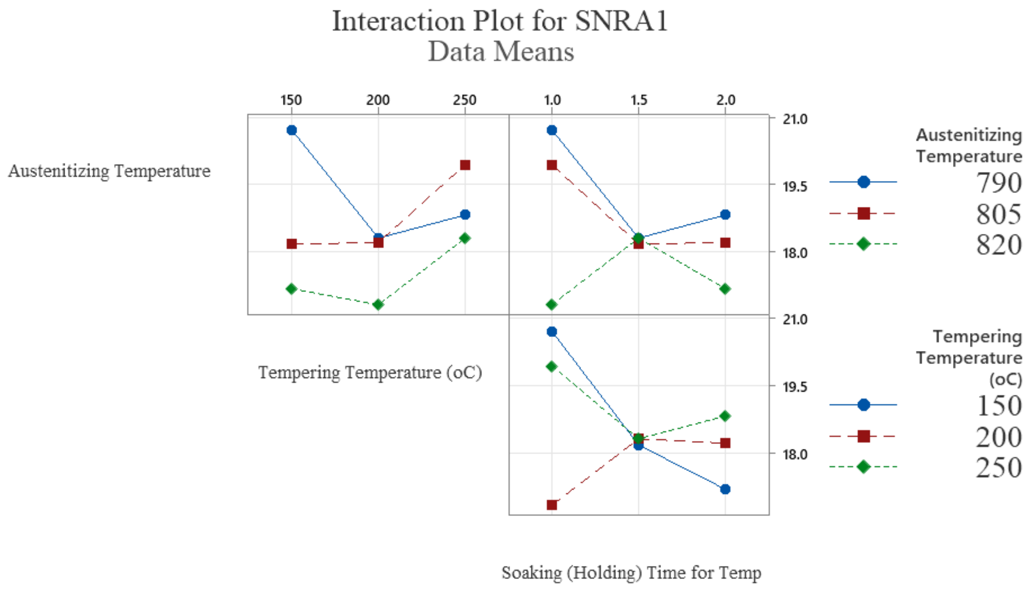

Figure 4.7 Interaction plot for impact toughness signal to noise ratio

4.7.1 Interaction Plot Analysis of Tempering temperature and soaking time for tempering

Depending on the figure 4.7 above the following discussion is present.

- The impact toughness of the sample is maximum, medium and minimum at tempering temperature of 150 ^{o}C and soaking time for tempering of 1 hour, 1.5 hour and 2 hour respectively.
- At tempering temperature of 200^{o}C, the impact toughness is maximum, medium and minimum at soaking time for tempering of 1.5 hour, 2 hour and 1 hour, respectively.
- When the tempering temperature is 250^{o}C, the impact toughness is maximum, medium and minimum at soaking time for tempering of 1hour, 2 hour and 1.5 hour, respectively.

4.7.2 Interaction Plot Analysis of Austenitizing temperature versus Tempering temperature

According to figure 4.7 above one can discussed as the following

- At Austenitizing temperature of 790^{o}C, the impact toughness is maximum, medium and minimum at tempering temperature of 150 ^{o}C, 250 ^{o}C and 200 ^{o}C , respectively

- When Austenitizing temperature of 805°C, the impact toughness is maximum, medium and minimum at tempering temperature of 250 °C, 200 °C and 150 °C , respectively
- The impact toughness is, maximum, medium and minimum at Austenitizing temperature of 820°C and at tempering temperature of 250 °C, 150 °C and 200 °C , respectively

4.7.3 Interaction Plot Analysis of Austenitizing temperature versus soaking time for tempering

Based on figure 4.7 the following points listed out

- The impact toughness is maximum, medium and minimum at Austenitizing temperature of 790°C and at soaking time for tempering of 1 hour, 2 hour and 1.5 hour, respectively.
- At Austenitizing temperature of 805°C, the impact toughness is maximum, medium and minimum at soaking time for tempering of 1 hour, 2 hour and 1.5 hour, respectively.
- When Austenitizing temperature of 820°C, the impact toughness is maximum, medium and minimum at soaking time for tempering of 1.5 hour, 2 hour and 1 hour, respectively.

4.8 Contour Plot of Austenitizing temperature versus Tempering temperature

Figure 4.8 bellow shows that the influence of Austenitizing temperature and temperature on impact toughness. MINITAB 2022 contour plot revealed that, the higher the Austenitizing temperature have, a significant influence on the decreasing impact toughness.as long as it is possible to having improved impact toughness within the Austenitizing temperature of 790°C-802°C at tempering temperature of 150°C-180°C and 225°C-250°C. On the other hand, when the Austenitizing temperature is 790oC-820oC there is a less impact toughness at tempering temperature of 180°C-225°C.

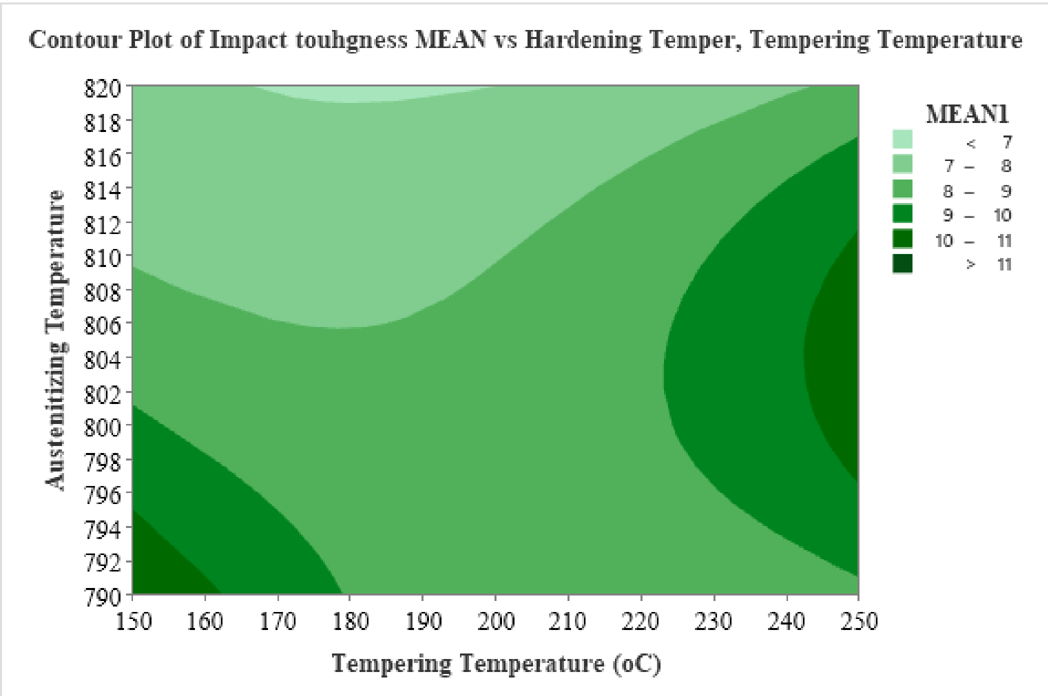

Figure 4.8 Influence of time versus speed on the mean values of compression strength

4.9 Wear Test Result

As discussed in section 2.8.3 Cold work tools like dies and punches expose to abrasive wear. According to wear test procedure, the nine-test or 18 specimen measured their balance after and before wear test and calculated the mass loss and volume loss within 5 minutes and get the result as shown table 4.10 and 4.11.All specimens have mass 2.59766gram before wear.

Mass loss=Mass (g) before wear -Mass (g) after wear (4.1)

For Group 1.1 sample - Mass before wear=2.59766g, Mass after wear = 2.57877g

Mass loss = Mass before wear-Mass after wear

= 2.59766g-2.57877g

= 0.01889g

Volume loss, mm^3 = $\frac{\text{mass loss,g}}{\text{density,g/cm3}}$ x1000 (4.2) [34]

= $\frac{0.01889\text{ g}}{7.66\text{g/cm3}}$X1000

=2.46606 mm^3

Using the above equation (4.2) all results calculated as seen in the following table

Table 4.10 Group 1-volume loss results within 5minutes

Group	Mass (g) Before wear test	Mass (g) After wear test	Mass (g) loss	Volume (mm^3) loss Group 1
1.1	2.59766	2.57877	0.01889	2.46606
2.1	2.59766	2.57876	0.01890	2.46736
3.1	2.59766	2.57869	0.01897	2.47650
4.1	2.59766	2.57870	0.01896	2.47520
5.1	2.59766	2.57876	0.01890	2.46736
6.1	2.59766	2.57869	0.01897	2.47650
7.1	2.59766	2.57876	0.01890	2.46736
8.1	2.59766	2.57869	0.01897	2.47650
9.1	2.59766	2.57875	0.01891	2.46867

Table 4.11 Group 2- volume loss results within 5minutes

Group	Mass (g) Before wear test	Mass (g) After wear test	Mass loss (g)	Volume loss Group 2
1.2	2.59766	2.5787	0.01896	2.4752
2.2	2.59766	2.57869	0.01897	2.4765
3.2	2.59766	2.57875	0.01891	2.46867
4.2	2.59766	2.57877	0.01889	2.46606
5.2	2.59766	2.5787	0.01896	2.4752
6.2	2.59766	2.57876	0.0189	2.46736
7.2	2.59766	2.57869	0.01897	2.4765
8.2	2.59766	2.57876	0.0189	2.46736
9.2	2.59766	2.57869	0.01897	2.4765

Wear resistance of the material test results and calculated values of S/N ratio and MEAN registered in the following table 4.12 from the nine trials experiment.

Table 4.12 wear resistance test results for the trials with their calculated S/N and MEAN results within 5minutes

Number of Run	Austenitizing Temperature (^oC)	Tempering Temperature (^oC)	Soaking (Holding) Time for Tempering (Hours)	Volume loss /mm^3/		MEAN Volume loss /mm3/	Signal to noise ratio S/N
				Group 1	Group 2		
1	790	150	1	2.46606	2.4752	2.47063	-7.85617
2	790	200	1.5	2.46736	2.4765	2.47193	-7.86074
3	790	250	2	2.47650	2.46867	2.472585	-7.86304
4	805	150	1.5	2.47520	2.46606	2.47063	-7.85617
5	805	200	2	2.46736	2.4752	2.47128	-7.85845
6	805	250	1	2.47650	2.46736	2.47193	-7.86074
7	820	150	2	2.46736	2.4765	2.47193	-7.86074
8	820	200	1	2.47650	2.46736	2.47193	-7.86074
9	820	250	1.5	2.46867	2.4765	2.472585	-7.86304

The MEAN values of wear resistance of the material is higher at the experiment combinations of, Austenitizing temperature 805 ^oC, tempering temperature 150 ^oC and soaking time for tempering 1hour. The wear resistance of the material is lower at the combinations of Austenitizing temperature 820 ^oC, tempering temperature 250 ^oC and soaking time for tempering 2hour. The variation in tempering temperature affects the wear resistance of the material significantly as shown in the table 4.13 below.

Table 4.13 Response table for MEAN smaller is better

Level	Austenitizing Temperature	Tempering Temperature	Soaking (Holding) Time for Tempering
1	2.472	2.471	2.471
2	2.471	2.472	2.472
3	2.472	2.472	2.472
Delta	0.001	0.001	0.000
Rank	2	1	3

From the table 4.13 we can be see that the influence rank of each factor on the wear resistance response can be interpreted as the effect of tempering temperature on the wear resistance takes the first rank, whereas Austenitizing temperature and soaking (holding) time for tempering takes the second and third rank respectively.

4.10 Main Effect Plots

The main effect plot is uses signal to noise ratio data and confirmed by plot of MEAN.

4.10.1 Main Effect Plot for wear resistance S/N Ratio

As shown in the figure 4.11 below, for smaller is better main effect plot for S/N ratio are higher at Austenitizing temperature, Tempering temperature and Soaking time for tempering of 805oC,150oC and 1 hour respectively.

The S/N ratio of wear resistance of the material is minimum at Austenitizing temperature, tempering temperature and soaking time for tempering of 820^{o}C, 250^{o}C and 1.5 hour respectively. The objective is getting of minimum response for volume loss, so, based on main effect plot for S/N ratio the optimum combinations are selected as Austenitizing temperature, Tempering temperature and Soaking time for tempering of 805^{o}C, 150^{o}C and 1 hour respectively.

Table 4.14 Optimum combination of input parameters for wear resistance of the material response only

Austenitizing temperature	Tempering temperature	Soaking time for tempering
805^{o}C,	150^{o}C	1hour

From the table 4.15 we can be see that the influence rank of each factor on the material wear resistance response can be interpreted as the effect of tempering temperature on the wear resistance takes the first rank, whereas Austenitizing temperature and soaking (holding) time for tempering takes the second and third rank respectively

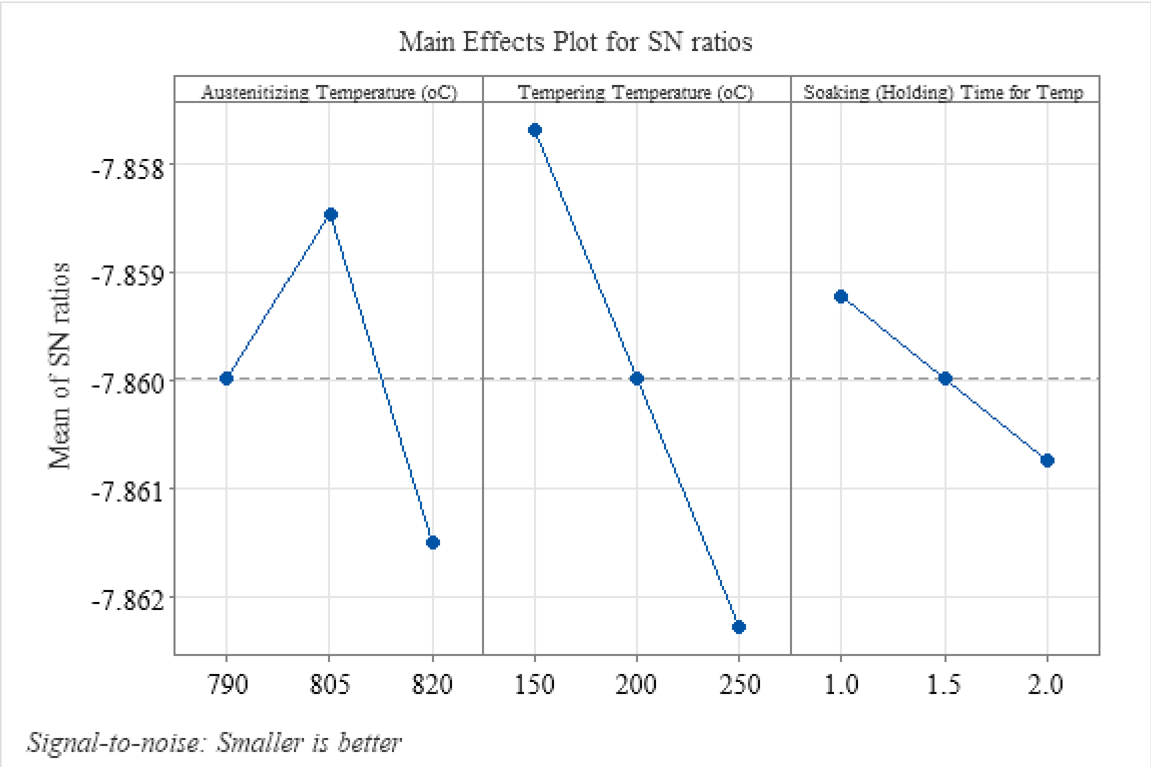

Figure 4.9 Main effect plot for S/N ratio for wear resistance of the

Table 4.15 Response table for Signal to Noise Ratio smaller is better for wear resistance of the material

Level	Austenitizing Temperature (^oC)	Tempering Temperature (^oC)	Soaking (Holding) Time for Tempering
1	-7.860	-7.858	-7.859
2	-7.858	-7.860	-7.860
3	-7.862	-7.862	-7.861
Delta	0.003	0.005	0.002
Rank	2	1	3

4.10.2 Main Effect Plot for wear resistance of the material MEAN

Main effect plot for Means is a plot that describes average volume loss value based on the average response value of group one and group two from the experiment. Main effect plot for Means also confirms the result of signal to noise ratios and predict the optimum process parameter with the inverse of S/N ratio. Because MEAN takes the larger number for the graph but signal to noise ratio graph takes the minimum values of the response as an optimum value, since smaller volume loss shows good wear resistance of the material.

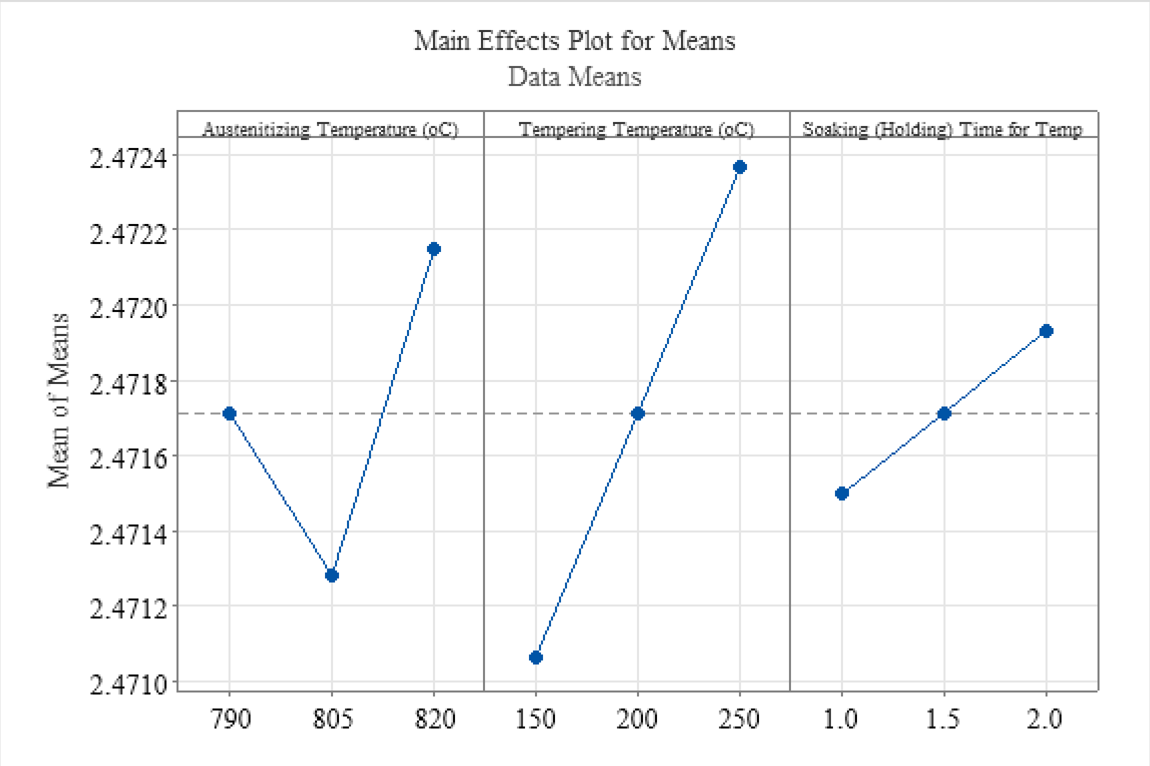

Figure 4.10 Main effect plot for wear resistance MEANs

As shown in the figure 4.12 above, wear resistance of the material is minimum at Austenitizing temperature, tempering temperature and soaking time for tempering of 820^{o}C, 250^{o}C and 1.5 hour respectively. The objective is getting of minimum response for volume loss, so, based on main effect plot for wear resistance MEANs, the optimum combinations are selected as Austenitizing temperature, tempering temperature and soaking time for tempering of 805°C, 150°C and 1 hour respectively.

4.11 Interaction plot Analysis for wear resistance of the material Signal to Noise Ratio

Figure 4.13 shows the effects of Austenitizing temperature, tempering temperature and soaking time on wear resistance of the material according to MINITAB 2022.

4.11.1 Interaction Plot Analysis of Austenitizing temperature and soaking (holding) time for tempering on the wear resistance of the material

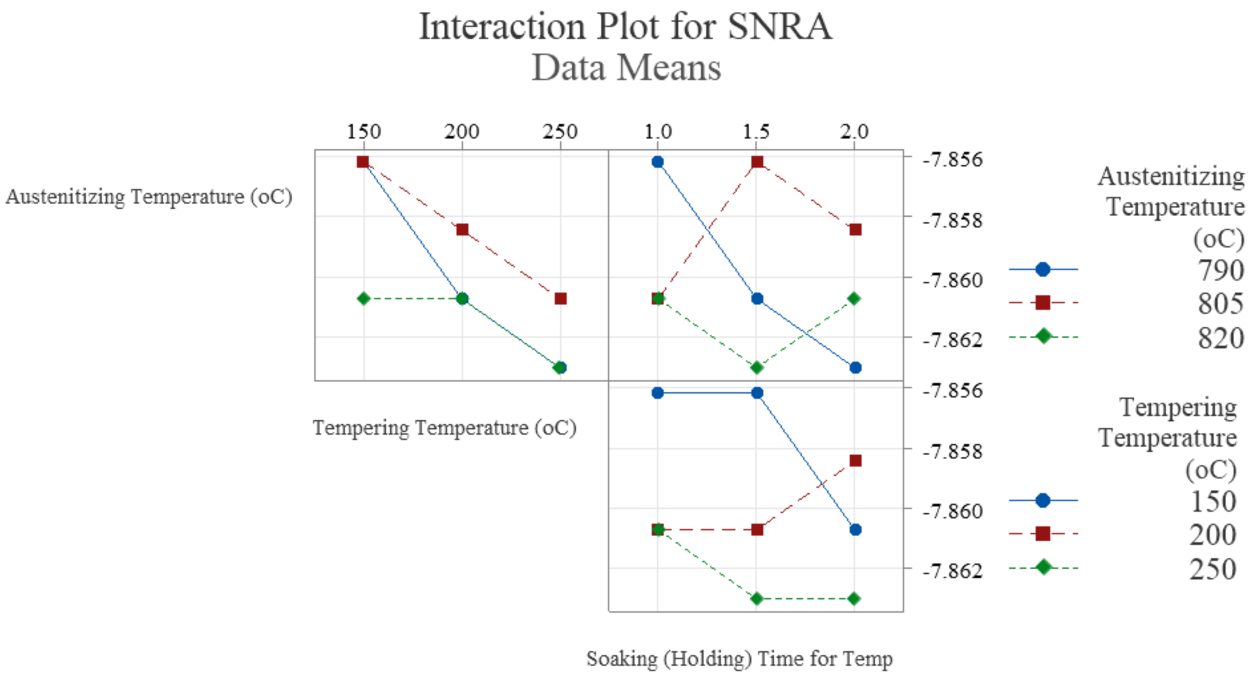

Figure 4.11 Interaction plot analysis for S/N on the wear resistance of the material

- ❖ Wear resistance of the material is minimum at a soaking time of 2 hour and Austenitizing temperature of 790°C and wear resistance of the material is maximum at a soaking time of 1.5 with Austenitizing temperature 805°C.
- ❖ At Austenitizing temperature of 820°C, the wear resistance is maximum, medium and minimum at soaking time of 1 hour, 2hour and 1.5 hour respectively.
- ❖ When the Austenitizing temperature is 805°C, the wear resistance is maximum, medium and minimum at a soaking time of 1 hour, 2 hour and 1.5 hour respectively.
- ❖ When Austenitizing temperature is at 790°C, wear resistance is maximum, medium and minimum at a soaking time of 2 hour, 1.5 hour and 1 hour respectively.

4.11.2 Interaction Plot Analysis of tempering temperature and soaking (holding) time for tempering on the wear resistance of the material

- At tempering temperature of 150 ^oC, the wear resistance of the material is maximum at soaking (holding) time of 2 hour and equal minimum at soaking (holding) time 1 hour and 1.5 hour respectively.
- When the tempering temperature is 200 ^oC, the wear resistance of the material is maximum, medium and minimum at soaking (holding) time of 1 hour, 1.5 hour and 2 hour respectively.
- At tempering temperature of 250 ^oC, the wear resistance is equal maximum at 2 hour 1.5 and minimum at soaking (holding) time of, 1 hour.

4.11.3 Interaction Plot Analysis of Austenitizing Temperature and Tempering temperature on wear resistance of the material

- At a tempering temperature of 150 ^oC, the wear resistance of the material is maximum at 820^oC, and equal minimum at Austenitizing temperature of, 790 ^oC and 805^oC respectively.
- When the tempering temperature is 200 ^oC, the wear resistance is maximum and minimum at the Austenitizing temperature of 805 ^oC, and 820 ^oC respectively.
- At 250 ^oC tempering temperature, the wear resistance is maximum, and minimum ate the Austenitizing temperature of 805 ^oC, and 820 ^oC respectively.

4.12 Contour Plot of Austenitizing Temperature versus Tempering temperature for wear resistance

Contour plot shows, the response of the factor at any point within the rage of the factor as shown in the figure 4.14 below.

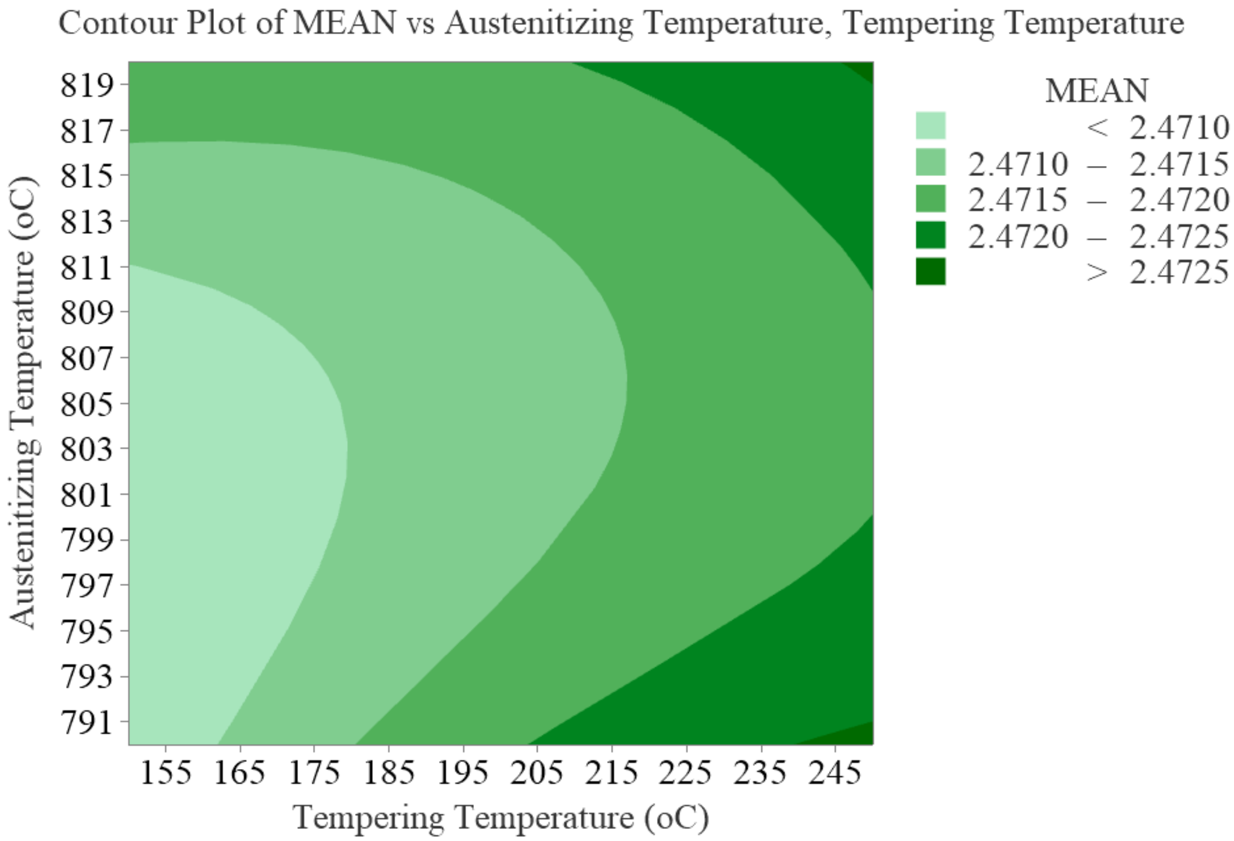

Figure 4.12 Influence of Austenitizing temperature versus tempering temperature on the MEAN values of volume loss

- The volume loss is minimum or less than 2.4710 mm^3 within the range of tempering temperature 150°C -175°C and at the Austenitizing temperature range of 790 °C-811°C, which means wear resistance of the material is higher within this range.
- The volume loss is maximum or greater than 2.4725mm^3 within the range of tempering temperature 240°C-250°C and within the range of Austenitizing temperature 790°C-791°C and 819°C-820°C, which means the material wear resistance is low at those range.

4.13 Grey relation analysis for multi-optimization

For this investigation Taguchi, technique used to perform multi-objective optimization in order to identify the process parameter combination that will optimize the overall quality features (the hardness, the toughness and the wear resistance of the material). Grey relational analysis method is one of the method that used to evaluate the degree of correlation between the sequences. By assigning Grade Relational Grade (GRG) to discrete output responses, it utilized to combine several output responses into a single output response [39].

Out the nine experiments, signal to noise ratio (S/N), the optimum combination of process parameter determined in terms of Grade Relational Grade (GRG) based on the higher-is-better criteria using the Minitab 2022 software.

As show in the Table 4.16 below, the experimental data is normalized, using Eqn. (4.3) based on the larger-is-better criterion for hardness and impact toughness, but Eqn. (4.4) smaller -is-better for wear resistance. Then, using Equations (4.5) and (4.6), respectively, Grey Relational Coefficients (GRC) and Grey Relational Grades (GRGs) calculated. As indicated in Table 4.17, mean GRG values derived from GRC values for each parameter for each level value. Figure 4.16 displays a main effect plot of each process variable on the mean GRG at various levels. Response mean values must obtained for each experiment run in order to determine the impact of each variable on the output. A summary of these results provided in Table 4.16 below.

4.13.1Data Normalization

Normalization is a transformation carried out on a single data input to scale the data into an appropriate range and distribute it uniformly for subsequent analysis. The following formula normalizes yij as Zij ($0 \leq Zij \leq 1$) in order to prevent the impact of using different units and to reduce variability. To make the value of this array close to 1, a suitable value subtracted from the values in the same array. S/N ratio calculated using Equation 4.3 and 4.4 below, where larger is better and smaller is better respectively. In Table 4.16, the normalized values displayed

$$Z_{ij} = \frac{y_{ij} - \min(y_{ij})}{\max(y_{ij}) - \min(y_{ij})} \tag{4.3}$$

$$Z_{ij} = \frac{\max(y_{ij}) - y_{ij}}{\max(y_{ij}) - \min(y_{ij})} \tag{4.4}$$

Where y_{ij} Corresponding response

Below is an example computation on data normalization for hardness, impact toughness and wear for trial number one.

$$Z_{\text{Hardness (1)}} = \frac{(36.1904 - 35.5806)}{(36.3549 - 35.58060)} = \underline{\underline{0.788}}$$

$$Z_{\text{Impact (1)}} = \frac{(20.72 - 16.83540)}{(20.72 - 16.8354)} = \underline{\underline{1}}$$

$$Z_{\text{Wear (1)}} = \frac{(-7.85617 - (-7.85617))}{(-7.85617 - (-7.86304))} = \underline{\underline{0}}$$

For deviation sequence

$$\Delta oj_{\text{Hardness (1)}} = ||\ 1 - 0.788\ || = \underline{\underline{0.212}}$$

$$\Delta oj_{\text{Impact (1)}} = ||\ 1 - 1\ || = \underline{\underline{0}}$$

$$\Delta oj_{\text{Wear (1)}} = ||\ 1 - 0\ || = \underline{\underline{1}}$$

Table 4.16 S/N ratio values and normalized S/N ratio values

Trial No.	S/N ratios			Normalized values			Deviation Sequence (Δoj)		
	Hardness	Impact toughness	Wear resistance	Hardness	Impact toughness	Wear resistance	Hardness	Impact toughness	Wear resistance
1	36.1904	20.72	-7.85617	0.788	1.000	0.000	0.212	0.000	1.000
2	35.9691	18.3171	-7.86074	0.502	0.381	0.653	0.498	0.619	0.347
3	35.605	18.8295	-7.86304	0.032	0.513	0.981	0.968	0.487	0.019
4	36.3549	18.1804	-7.85617	1.000	0.346	0.000	0.000	0.654	1.000
5	35.986	18.2213	-7.85845	0.524	0.357	0.326	0.476	0.643	0.674
6	35.847	19.948	-7.86074	0.344	0.801	0.653	0.656	0.199	0.347
7	36.2575	17.1913	-7.86074	0.875	0.092	0.653	0.125	0.908	0.347
8	36.1405	16.8354	-7.86074	0.723	0.000	0.653	0.277	1.000	0.347
9	35.5806	18.3171	-7.86304	0.000	0.381	0.981	1.000	0.619	0.019
Max	36.35490	20.72000	-7.85617	1.0	1.0	1.0	1.0	1.0	1.0
Min	35.58060	16.83540	-7.86304	0.0	0.0	0.0	0.0	0.0	0.0

4.13.2Grey relational coefficient (GRC)

The next part of analysis are calculation of the grey relational co-efficient for the normalized S/N ratio values.

$$\gamma(y_o(\mathrm{k}), y_i(\mathrm{k}) = \frac{\Delta \min + \xi \Delta \max}{\Delta_{\mathrm{oj}}(\mathrm{k}) + \xi \Delta \max} \tag{4.5}$$

Where 1. i = 1, 2...n; k = 1, 2...m, n is the number of experimental data items and m is the number of responses.

2. y_o (k) is the reference sequence (y_o (k) =1, k=1, 2...m); y_j (k) is the specific comparison sequence.

3. Δ_{oj} = || y_o (k) - y_j (k) || = the absolute value of the difference between y_o (k) and y_j (k)

4. Δ Min = $\min\limits_{\forall j \epsilon i} \min\limits_{\forall k}$ || y_o(k) - y_j(k) || is the smallest value of y_j(k).

5. Δ Max = $\max\limits_{\forall j \epsilon i} \max\limits_{\forall k}$ || y_o(k) - y_j(k) || is the largest value of y_j(k).

6. ξ is the distinguishing coefficient, which is defined in the range 0 ≤ ξ ≤ 1 (the value may adjusted based on the practical needs of the system)

An example calculation on grey relational coefficient (GRC) of hardness, impact toughness and wear resistance of the material for trial number one given below and the values are tabulated in Table 4.17.

$$\gamma_{\text{i hardness (1)}} = \frac{(0 + (0.5*1))}{(0.212 + (0.5*1))} = \underline{\underline{0.702}}$$

$$\gamma_{\text{i impact (1)}} = \frac{(0 + (0.5*1))}{(0 + (0.5*1))} = \underline{\underline{1}}$$

$$\gamma_{\text{i wear (1)}} = \frac{(0 + (0.5*1))}{(1 + (0.5*1))} = \underline{\underline{0.333}}$$

4.13.3 Grey relation grade (GRG)

The grey relational grades ($\overline{\gamma_J}$) determined by taking average of the GRC related to every observation as presented in equation 4.6.

$$\overline{\gamma_J} = \frac{1}{k}\sum_{i=1}^{n}\gamma_{ij} \qquad (4.6)$$

Where $\overline{\gamma_J}$ the grey relational grade for the jth experiment and k is the number of performance characteristics. The better the product quality, the higher the grey relational grade; as a result, the factor influence may be evaluated using the grey relational grade, and the optimum level for each controllable factor can be established.

For example, to estimate the effect of factor i, we calculate the average of grade values (AGV) for each level j, denoted as AGV_{ij}, then the effect, E_i, is defined as:

$$E_i = \max(AVG_{ij}) - \min(AVG_{ij}) \qquad (4.7)$$

If the factor i is controllable, the best level j*, is determined by

$$j^* = \max_j (AVGij) \qquad (4.8)$$

Grey relational grade can calculate using Eqn 4.6 and its value tabulated in the Table 4.17.

$$\overline{\gamma_J}_{(1)} = \frac{1}{3}*(0.702 + 1+0.333) = \underline{\underline{0.678}}$$

Table 4.17 Grey relational coefficient and grey grade values

Trial No.	Grey relational coefficient			Grey grade
	Hardness	Impact toughness	Wear resistance	
1	0.702	1.000	0.333	0.678
2	0.501	0.447	0.590	0.513
3	0.340	0.507	0.963	0.603
4	1.001	0.433	0.333	0.589
5	0.512	0.437	0.426	0.458
6	0.433	0.715	0.590	0.579
7	0.799	0.355	0.590	0.581
8	0.644	0.333	0.590	0.522
9	0.333	0.447	0.963	0.581

The mean of selected GRGs calculated using the procedure above and assembled to create the response table shown in Table 4.18. The grades in the response table serve as a measure of the correlation between the reference sequence and comparability sequence of GRA. Higher values of the mean of GRGs indicate a strong correlation. It is therefore possible to determine the combination of ideal parameters that maximizes overall response using the response table for GRGs in Table 4.18. According to Table 4.18, the highest grey relationship grades are A2, B2 and C3, Therefore, it can be said that 805°C of Austenitizing temperature, 200°C tempering temperature and 2 hour soaking time for tempering are the process' optimal conditions.

Table 4.18 Response table for signal to noise ratio for grey relational grade

Level	Austenitizing Temperature (^oC)	Tempering Temperature (^oC)	Soaking (Holding) Time for Tempering
1	4.522	4.230	4.589
2	**5.376**	**6.076**	5.037
3	5.027	4.619	**5.298**
Delta	0.853	1.846	0.708
Rank	2	1	3

4.13.4 Estimation of optimum levels of input process parameters

The maximum value of GRG chosen for each process parameter after calculating the average value of GRG for each level of the process parameters. The bold GRG values in Table 4.18 are the highest values for each process parameter across the two levels. For superior performance characteristics, use the 805^oC of Austenitizing temperature, 200^oC tempering temperature and 2-hour soaking time for tempering are the process' optimal conditions as indicated in Figure 4.15. Figure 4.15 demonstrates that the process parameters' optimum values that result in the highest GRG values.

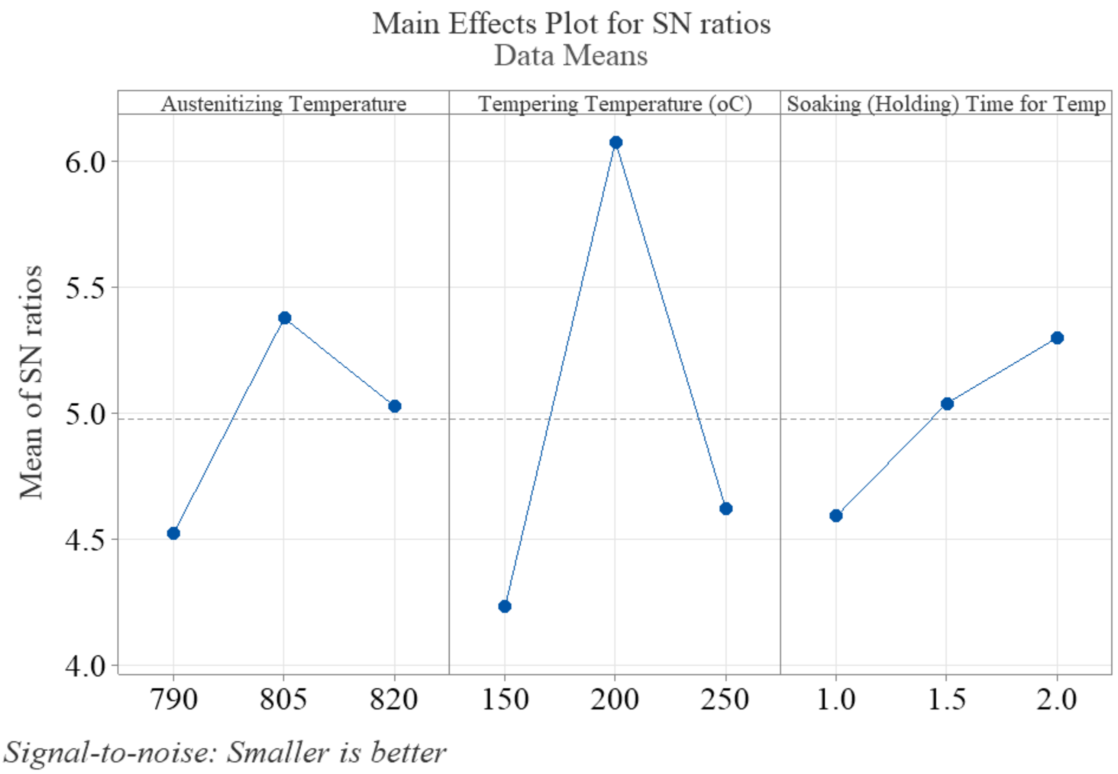

Figure 4.13 Main effect plot for signal to noise ratio for Grey Grade

This combination is found in the experiment run number 5.Generally, the optimum combinations of control factors for hardness, Impact energy and Volume loos /Wear resistance/ are describes in Table 4.19 below.

Table 4.19 optimum combination result of hardness, impact energy and wear rate for application of die making using AISIO2 steel material.

Factor	Response		
	Hardness (HRC)	Toughness Impact energy(J)	Volume loos (mm$^{3)}$/mass loos (g)/
Austenitizing temperature (805°C), 30 min for each	63	8.25	2.47128/0.0189/
Tempering temperature (200°C)			
Soaking (Holding) time for tempering (2 hours)			

Table 4.20 optimum combination result of hardness, impact energy and wear rate for application of die making using AISIO2 steel material.

Number of Run	Austenitizing Temperature (°C)	Tempering Temperature (°C)	Soaking (Holding) Time for Tempering (Hours)	Hardness (HRC)	Impact toughness (J)	Wear resistance (mm^3)
1	790	150	1	64.500	11.00	2.47063
2	790	200	1.5	62.875	8.25	2.47193
3	790	250	2	60.335	8.75	2.472585
4	805	150	1.5	65.750	8.50	2.47063
5	805	200	2	63.000	8.25	2.47128
6	805	250	1	62.000	10.50	2.47193
7	820	150	2	65.000	7.25	2.47193
8	820	200	1	64.125	7.00	2.47193
9	820	250	1.5	60.125	8.25	2.472585

The parent material gives information only the range of Austenizing temperature and the working HRC. However, this information is not enough to use the material for die purpose as it is, instead there must be tempering temperature, soaking time and respective toughness. Therefore, the generated result used to have more information about the material and used to select the optimum one. This result generated according to Taguchi Grey relation analysis (GRA) after running nine different experiments. The gray relational method is a complex methodology that based on a series of mathematical calculations and comparisons, which may not always be the most efficient or cost-effective way to achieve the desired outcome. However, it is important to note that the correctness of the procedure used in applying the gray relational method is essential to ensure that the results obtained are reliable and accurate. Even if the results obtained are not economical, it is still important to follow the correct procedure in order to ensure that the analysis is valid and can be used to inform the decision-making process as the GRA has its own procedure and principles. Generally, the result 63 HRC means within the range of the working hardness of the material, the toughness result of the material is 8.25J which is greater than 6J which is the minimum toughness of the die tool and according to George Vander Voort, if the die blocks are handed and tempered to 55 to 68 HRC will have, a good wear resistance so, it is valid data for die block design [4][6][21][22][46]. However, from the point of view of the design principles, for the optimum experimental combination, it is possible to select another optimum run from the table 4.20 in order to achieve the desired output economy wise.

Accordingly, experiment number 2 conducted with a minimum cost since it has the lowest austenitizing Temperature (790^{o}C) and lowest holding time (1.5 Hr.). Additionally, a negligible difference in experiment number 5 has been found as compared to experiment number 2. Therefore, experiment 2 is preferred to be economical in comparison to experiment 5.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Depend on the material parent material, AISI O 2 steel, experimental investigation done in order to get the optimum combination of heat treatment process parameters for effect steel die design material. This study use heat treatment to alter the hardness, impact toughness and wear resistance behavior of the parent material. The heat treatment processes were Austenizing, tempering and quenching. The study uses 36 specimens, where two specimens were used for each experimental run of the targeted study data.

After retrieving experimental data related to hardness, impact toughness and wear resistance of the parent material a post-analysis done to identify the optimum combination parametric data. The analysis results show that tempering temperature has a significant effect on altering the hardness, impact toughness and wear resistance of the material.

- Austenizing temperature 8050C
- Tempering temperature 200^{0}C
- Soaking time for tempering 2 hours

Therefore, the generated mechanical properties of the parent material are-

- Hardness 63HRC,
- Toughness 8.25J
- Wear resistance (volume loos /Mass loos/) (2.47128mm^{3}/0.0189gram/)

Additionally, a negligible difference in experiment number 5 has been found as compared to experiment number 2. Therefore, experiment 2 is preferred to be economical in comparison to experiment 5.

Austenizing temperature 790^{0}C

Tempering temperature 200^{0}C

Soaking time for tempering 1.5hours

Therefore, the generated mechanical properties of the parent material are-

Hardness 62.875HRC,

Toughness 8.25J

Wear resistance (volume loos /Mass loos/) (2.47193mm3/0.0189gram/)

Because the result has a minimum difference with the optimum result.

.

5.2 Recommendation

It is important to use optimal heat treatment process parameter during heat treatment setup for the design. This study has identified potential combination parameter of heat treatment of AISI O2 for steel die block design, but it can be used to heat treat the punch part also.

5.3 Future works

It is important to find other mechanical properties at the optimum condition of this study, hence further study can be done with this regards.

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Appendix

የኢ.ፌ.ዲ.ሪ መከላከያ ሚኒስቴር
በመከላከያ ዩኒቨርስቲ የኢንጅነሪንግ ኮሌጅ
F.D.R.E Ministry of Defense
Defense University, College of Engineering

ቀን Oct 18/22
Date:
ቁጥር MIG.4/St20/J/436/22
Ref.No

To: - Manufacturing Industry Development Institute
Manufacturing Technology and Engineering
Industry Research & Development Center
Addis Ababa

Subject: - Regarding K460 (AISIO$_2$) Steel Testing.

Upon your request dated on Oct.18/2022 to perform impact test of K460 (AISIO$_2$) Steel for you post graduate student (Sisay Kebede Tlahun) the respective test is conducted in our Material testing laboratory.

Accordingly the analysis is completed as per request and hence, you find the report attached here

Attached: - 01

With regards

L.Col Yeshitela shiferaw (Dr)

Defance university college of Engineering

Academic Dean (Acting)

ስልክ ፖ.ሳ.ቁ ፋክስ ኢ-ሜይል dec_cs@dec.edu.et ቢሾፍቱ-ኢትዮጵያ
Tel. 251-11433-27-11 P.O. Box 1041 Fax 251-11433-86-08 Website: www.dec.edu.et Bishoftu-Ethiopia

Impact test result					
No.	Sample Name		Energy Absorbed in(J)	Average	Rise Angle in degree
1	1	S1	10	11	124
		S2	12		119
2	2	S1	8.5	8.25	128
		S2	8		129
3	3	S1	9	8.75	126
		S2	8.5		128
4	4	S1	7	8.5	132
		S2	10		124
5	5	S1	9	8.25	126
		S2	7.5		131
6	6	S1	12.5	10.5	118
		S2	8.5		128
7	7	S1	7.5	7.25	131
		S2	7		132
8	8	S1	7.5	7	131
		S2	6.5		134
9	9	S1	8	8.25	129
		S2	8.5		128

Name of tester:-Manwesnot Tsegaw

Signature ____________

Date:-18/10/2022

Approved by :- (L/Col) Simachew Andualem (Metallurgical and Materials Engineering department head)

Signature ____________

Date:-18/10/2022

	MANUFACTURING TECHNOLOGY AND ENGINEERING INDUSTRY RESEARCH AND DEVELOPMENT CENTER	QMS.TM.03A ; Rev. 0
	HARDNESS TEST	Effective Date: January 2019

Date: 17/10/2022

Report No: NDT/HT005/15
To: Sisay Kebede Tilahun
Sub: Test Report
Ref No: EALBM/CEO/339/2022

No	*Name of equipment*	*Made in*	*Specification*	*Remark*
1	Fours nagat- Furnace	France	1200°C-Maximum Heating Temperature	Used for hardening purpose
2	Lenton -Furnace	England	1200°C-Maximum Heating Temperature	Used for Tempering Purpose
3	Agitator Motor	Czechoslovakia	930rpm	Used to agitate the oil
4	BROOKS -Hardness tester	England	90-Maximum HRC	Used to measure the hardness of the Trial

Number of Run	Hardening Temperature (°C)	Tempering Temperature (°C)	Soaking (Holding) Time for Tempering (Hours)	Hardness/HRC/ Trial 1	Hardness/HRC/ Trial 2	MEAN of Hardness /HRC/
1	790	150	1	64	65	64.5
2	790	200	1.5	63.25	62.5	62.875
3	790	250	2	61.67	59	60.335
4	805	150	1.5	66.75	64.75	65.75
5	805	200	2	63.5	62.5	63
6	805	250	1	62.5	61.5	62
7	820	150	2	65.5	64.5	65
8	820	200	1	64.25	64	64.125
9	820	250	1.5	60.5	59.75	60.125

Tested by	**Cheeked by**	**Approved by**
Name Nardos Mekoya	Name Tewodros Alebachewu	Name Dejene Legese
Date :- 17/10/2022	Date :- 17/10/2022	Date :- 17/10/2022
Signature :-	Signature :-	Signature :-

Yours Sincerely,

Laboratory testing and quality control directorate