



JOURNAL ON COMMUNICATIONS

ISSN:1000-436X

REGISTERED

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TO STUDY THE EFFECT OF HEAT TREATMENT ON MECHANICAL PROPERTIES AND MACHINABILITY OF TOOL STEEL D3

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Abstract— This research paper clarify about an examination of my venture is to assess the impact of different intensity therapy process on mechanical properties and machinability of material. Apparatus steel D3 is my material and CBN embed instrument is utilized for machining procedure on CNC machine. Correlation between harshness when customary intensity therapy process, and when cryogenic therapy process are laid out in subtleties, Similarly apparatus wear and chip morphology when regular intensity therapy process and cryogenic therapy process are additionally settled exhaustively. Consequence of mechanical properties after heat treatment cycle, for example, hardness and strength of material increment subsequent to playing out the convectional heat treatment process and cryogenic treatment process on material however mechanical properties acquired after traditional intensity therapy process are less great as contrast with mechanical properties got after cryogenic therapy process. Instrument wear and chip morphology estimated with various working variables. These functioning elements are cutting velocity, feed rate, profundity of cut and other significant variables and so on and feed rate are taken from 0.1 to 0.3 mm per insurgency and cutting pace is taken from 100 to 200 rpm yet profundity of cut is kept steady that is 0.3 mm. To examine the apparatus wear and chip morphology, checking electron microscopy (SEM) procedure is utilized and this large number of aftereffects of hardware wear and chip morphology are taken at 50, 100, 150, 300, 500 times amplification. What's more, mitutoyo surface unpleasantness analyzer is utilized to quantify the harshness of hardware steel D3 when treatment process. Reaction surface strategy method is utilized to decide ideal sitting of exploratory variables which produce ideal worth of reaction where trial esteem are cutting pace and feed rate. After the intensity therapy, microstructure of hardware steel D3 likewise estimated.

Keywords: mechanical properties, scanning electron microscopy (SEM), steel D3, cryogenic treatment, conventional heat.

1. INTRODUCTION

In heat treatment process, many cycle are utilized individually, for example, warming interaction, toughening process, cooling cycle and solidifying process and so on some time another kind of treatment process is utilized in heat treatment process which one is cryogenic treatment, some time cryogenic interaction fill in as extra cycle and some time cryogenic cycle work independently. Cryogenic treatment process is most recent treatment cycle of material in which material is cooled to extremely low temperature up to 77K and many gases are utilized in cryogenic treatment cycle, for example, nitrogen, oxygen, neon, hydrogen, helium, carbon pass on oxide and so on nitrogen gas is most generally utilized in cryogenic treatment process since nitrogen gas can reach to - 196 °C (77K) however in the event that we need temperature up to - 268 °C (5K) neon gas is utilized on the grounds that 5K temperature can't be get by utilization of nitrogen gas. Cryogenic treatment process assuage inner pressure/inward break of material.

Apparatus steel is likewise ordered on the essential of American iron and steel organization (AISI, for example, water solidifying instrument steel, hot work device steel , shock oppose instrument steel, oil solidifying instrument steel, tungsten rapid apparatus steel, chromium based instrument steel, molybdenum instrument steel and so on. Device steel D3 is ordered by AISI framework which is chromium hot work apparatus steel, UNS (bound together numbering framework) number of hardware steel D3 is T20813 which has 0.35%C, 5%Cr, 1%V, 1.5%Mo.the characterization arrangement of AISI orchestrate apparatus steel in various gatherings in light of the trait of hardware like intensity therapy , application and alloying . Each sort of hardware steel has different mechanical, warm and electrical properties. Properties of hardware steel principally rely on a compound which is higher in apparatus steel .And device steel properties pitifully rely on an amalgam which is least in apparatus steel.

Heat treatment process is the cycle by which we change the properties of material by change the precious stone

construction of material, (for example, change the FCC to BCC and so on) or we can say that we can acquire want properties of material by utilization of intensity therapy process. Heat treatment process comprise of some cycle, for example, warming interaction, full toughening process, recrystallization strengthening, stress help tempering, spheroidization tempering, cooling process, surface solidifying, case solidifying, work solidifying process, treating, normalizing and so on and heat treatment interaction can influence the whole work piece or just Surface or some district in material relies on the intensity therapy interaction and boundary utilized in heat therapy process.

Various sorts of intensity therapy process are practically same since all intensity therapy process requires the warming and cooling process. However, contrast is recognized by pace of warming and cooling. Heat treatment process is for the most part three stage process:

- Stage 1 - heat the metal(sample) to the craving temperature and guarantee the uniform temperature
- Stage 2 - hold the metal at high temperature for adequate time span as per prerequisite
- Stage 3 - cool the metal to room temperature

all kind of hardware steel are utilized in right put which rely upon properties of hardware steel and properties of hardware steel rely on the sythesis of compounds in device steel so we can say that properties of hardware steel rely on the piece of combinations accordingly we can say that when we change the creation of hardware steel then properties of hardware steel will likewise change and subsequently by changing the arrangement of hardware steel we can acquire the longing properties of hardware steel Properties of hardware steel additionally rely upon the gem design of hardware steel so we can likewise change the properties of hardware steel by utilizing the different sort of intensity therapy process since heat therapy process change the precious stone construction of material, for example, gem design of steel in iron carbon outline change from face focus cubic (FCC) to body focus cubic (BCC) during cooling of γ -austenite at eutectoid point in iron carbon graph.

In this review paper section I contains the introduction, section II contains the literature review details, section III contains the details types of heat treatment process, section IV describe the Cryogenic treatment, section V provide Machining of metals, section VI provide Machining of tool steel. Section VII provide Chip morphology; section VIII provide Results, section VIII provide conclusion of this research paper.

2. RELATED WORK

2.1 GENERAL

Writing audit is most significant part for any scientists since writing surveys show the how much review are acquired by analysts prior to beginning the undertaking. In any metal cutting cycle, cutting activity is related with shear strength of

workpiece. Higher shear strength foster the higher cutting power at different part of material and instrument thusly we select the best cutting condition for machining of any metal.

B. Podgornik, I. Paulin, B. Zajec, S. Jacobson, V. Leskovsek [3]: Material utilized in this study was a high exhaustion strength cold work steel with lower C and high W and Co content. To analyze the adequacy of DTC on break sturdiness and burden conveying limit, two more instrument prepares were utilized to be specific high C and V substance cold work device steel and one rapid steel. After examples were machined, they were vacuum heat treated utilizing nitrogen gas at a strain of 5 bar. To assess the impact of vacuum heat treatment three arrangements of vacuum heat treatment conditions, bringing about various hardness and break strength mixes were utilized and joined with profound cryogenic treatment. Following ends were made by this review: 1) if there should arise an occurrence of low carbon cold-work device steel (A1), DCT brings about incredibly further developed crack sturdiness while keeping up with high hardness. Then again, for high C cold-work instrument steel DCT makes a negative difference, while for rapid steel, DCT makes basically no difference. 2) DCT produces better needles like martensite and martensitic change joined by plastic twisting of essential martensite might be the purpose for the superior property of A1 steel. Modification in K_{Ic}/HRC proportion influences wear obstruction of cold-work device steel. Hardness is the principal boundary influencing rough wear opposition. 3) For the situation of burden conveying limit, hardness is the main boundary. To get great loadcarrying limit, hardness over 64 HRC is expected, with a break sturdiness of north of 10 MPam^{1/2} giving further improvement.

M. Perez, C. Rodriguez, F. J. Belzunce [4]: Hardness, strength, and durability of H13 steel submitted to various intensity therapies, including cryogenic therapies, were tried in their exploration work and the outcomes were made sense of in light of changes in microstructure. Examples were exposed to various extinguished and tempered medicines. Four unique warm medicines were applied called TT1, TT2, TT3 and TT4. They reasoned that elasticity and hardness have scarcely changed for the four applied warm medicines. Then again, there is a constructive outcome of the cryogenic medicines on the break strength of the prepares. TT2 (gas) and TT4 (oil) give separately 22.5% and 24% augmentation connected with their comparing medicines without cryogenic stage, TT1 and TT3. Extinguishing media likewise impacted the durability of the steel. Because of the impact of the cooling rate: oil extinguishing has higher durability than gas extinguishing. Extinguished and tempered H13 steel has a martensitic microstructure with very much scattered and finely disseminated carbides. SEM examination presumed that cryogenics create high inner pressure express that enacts the carbide nucleation in the primary periods of treating. This outcomes in a lot better and equitably circulated precipitation which likewise leads to a martensite with less carbon.

Marcos Perez, Francisco Javier Belzunce [7]: Cryogenic treatment was done on H13 apparatus steel utilized for hot

fashioning passes on, consequently deciding its mechanical properties ductile, hardness and crack durability tests. This paper makes sense of the exhibition of four different intensity therapies applied to H13. Two extinguishing media (gas and oil) and the impacts of a cryogenic stage were considered. Oil extinguishing by cryogenic treatment was done as the best one among each of the four medicines. The mechanical properties of the H13 steel were estimated by malleable, hardness and break tests. They reasoned that cryogenic treatment eminently further develops the break sturdiness of H13 steel. Cryogenic with gas and oil extinguishing produces 22.5% and 24% separately expansion in durability when contrasted with without cryogenic. So extinguishing medium additionally influences its strength. Profound cryogenic medicines diminish the held austenite content in H13 steel.

D Senthil Kumar, I Rajendran [5]: Effect of cryogenic treatment on the wear opposition property of En 19 steel was examined. Additionally, an examination on the impact of DCT (- 196 °C, 24 h), SCT (- 80 °C, 5 h) and CHT was finished by dry sliding wear test. Dry sliding wear test for low stacking and high stacking was noticed. The microstructures of CHT, SCT and DCT tests were concentrated by SEM. They have presumed that both DCT and SCT advance the change of held austenite to martensite, in this manner causing a critical expansion in wear obstruction. Wear obstruction was expanded by 118.38% for SCT tests and 214.94% for DCT when contrasted with CHT tests. Also, the expansion in wear obstruction of DCT tests is 44.39% concerning SCT tests. The least coefficient of contact is gotten in DCT tests treated at - 196 °C for 24 hr.

3. Types of heat treatment process

3.1. Annealing

Overall strengthening process is utilized to free the inner pressure from material and mellow the material then make the more malleable and refine the design of grains. Strengthening process is inverse of solidifying process which comprise of warming of metal to explicit temperature and afterward hold the metal at that temperature for adequate time span, then cool the metal to room temperature, cooling rate and cooling strategy rely on the which kinds of properties in metal we need. For example, if we need to make the increasingly more pliable the material then cooling rate should be extremely low as well as the other way around. In strengthening process, some metal are cooled in heater and some other metal are cooled covering in cinders.

3.2. Normalizing

Normalizing is the heat treatment type which is used for ferrous metals only. Normalizing is less differs from annealing. In normalizing, we heat the metal to high temperature in furnace then remove from furnace and then cool in air. The aim of normalizing and annealing is almost same because both annealing and normalizing are used to relieve the internal stress of metal and increase the ductility of metal but annealing increase the more ductility of metal as

compare to normalizing. Low carbon steel cannot be normalized.

3.3. Quenching or Hardening

In hardening, metals are heated to slightly above the critical temperature (from iron carbon diagram) and then cooled rapidly in water, oil, brine etc. hardening process increase the hardness, brittleness and strength of metal but decrease the ductility of metal. Hardness, brittleness and strength of harden metal depend mainly upon the cooling rate of heated metal. Hardness of metal can be increase by hardening process and by addition of carbon in metal. In general hardness of low carbon steel increase by addition of carbon while hardness of high carbon steel increase by hardening process.

3.4. Tempering

Normally, Tempering is performed after quenching because metal after quenching occurs very hard and gain some internal stress then to decrease the hardness of metal and relieve the internal stress, tempering is used. In general tempering process metal is heated to its lower critical temperature and then held for sufficient time period and then normally cool in air. The main aim of tempering occurs to increase the ductility of metal, to reduce the hardness and strength of metal and to obtain the desire physical properties. Tempering always follow the quenching. For soften the steel after quenching, tempering is used. Tempering is differ from quenching, hardening, annealing because in these all technique (other than tempering) metal is heated to upper critical temperature while in tempering, metal is heated to lower critical temperature. Amount of hardness lost in tempering depend upon the temperature at which metal is heated.

3.5. Case hardening

Case hardening also knows as surface hardening because case hardening is mainly used to increase the hardness of metal's surface and Case hardening also increase the wear resistance of metal's surface. Types of case hardening are flame hardening, cyaniding, carburizing, nitriding etc.

3.5.1. Carburizing

Carburizing is type of case hardening which is used for low carbon material. In carburizing process, metal is heated and then heated metal is put in carbon monoxide atmosphere due to which carbon atom penetrate into the surface of metal, depth of penetration depend upon the soaking period therefore hardness and wear resistance increase but strength, brittleness, ductility, toughness of core of metal do not change.

3.5.2. Cyaniding

Cyaniding is also types of case hardening process. Cyaniding is the fast and more efficient process than other case hardening process. Hardness obtain by cyaniding occurs highest than hardness obtain by other case hardening process. In cyaniding, metal is heated and then dipped in cyanide bath after that metal is rinsed to remove the residual cyanide.

3.5.3. Nitriding

This type of case hardening process also increase surface hardness which is mostly used for low carbon steel, in this process metal is heated in furnace which has an ammonia gas atmosphere. No quenching is required. In this process nitrogen diffuse in the surface of metal due to which hardness increase.

3.5.4. Flame hardening

Flame hardening process is other process of case hardening in which heating torch is used to heat the surface of metal and heating torch produce oxyacetylene flame which heat the metal surface to critical temperature and then quickly quenched by spray of water and cold the metal surface, properties of core of metal do not change. Flame hardening process can be manually control, mechanically control and automatically control process.

3.5.5. Aging or age hardening

Age hardening also known as precipitation hardening or particle hardening which is used to increase yield and tensile of non ferrous metal such as nickel, titanium, magnesium and stainless steel etc.

3.5.6. Induction hardening

Induction hardening is type of case hardening process in which metals are heated by electromagnetic induction and after that quenched, used for electrically conductive material and many steel to increase the surface properties.

4. Cryogenic treatment

Cryogenic treatment modifies the properties of metal by use of cryogenic temperature and change the crystal structure of material. Cryogenic treatment process works on third law of thermodynamics. Thermodynamics third law states that entropy at absolute zero temperature is zero, cryogenic treatment follow this principle for relieving the stresses in material. In cryogenic treatment, material is subjected to very low temperature for long time period. Cryogenic treatment do not substitute the heat treatment process, it is additional process for tool steel. Hardness of Most of material does not change by use of cryogenic treatment therefore we need to Tempering before cryogenic treatment to gain toughness and hardness of material and it affect the entire material.

4.1. Classification of cryogenic treatment

Cryogenic treatment process is mainly divided into two parts which depend on the temperature such as

- Shallow cryogenic treatment (SCT)
- Deep cryogenic treatment (DCT)

In shallow cryogenic treatment, tool steel keep at almost 190K temperature then brings to room temperature while in deep cryogenic Treatment, tool steel keep at almost 70K temperature then brings to room temperature. During the conventional heat treatment, we cool the materials till room temperature and then some austenite leave in material. Then

this retained austenite is transferred into martensite by use cryogenic treatment.

Liquefied gases are used in cryogenic treatment such as liquid neon, liquid nitrogen, liquid helium etc. nitrogen gas is most widely used in cryogenic treatment and easy purchasable in the world.

Boiling temperature of gases used in cryogenic (cryogens)

4.2. Cryogenic cycle

I. RAMP DOWN: - Temperature of material brings down to - 180 °C (93K) to relieve the thermal shocking of material.

II. SOAK: - In soak segment, keeps the material for hug interval of time. In soaking segment, crystal structure of material change at very slower rate therefore keeps the material in very low temperature for 12 to 15 hours in cryogenic furnace.

III. RAMP UP: - In ramp up segment, temperature of material brings to room temperature in 6 to 8 hours. Ramp up is important in cryogenic because when we increase the temperature of material with fast rate then some cracks take place therefore temperature of material increase with very slow rate.

IV. TEMPER RAMP UP: - In tempering ramp up segment, increase the temperature of material above the atmospheric temperature over sufficient time period. Tempering process is very important for ferrous material. Cryogenic temperature converts the all retained austenite into martensite due to strength and brittleness increase. Some time brittleness of material highly increase therefore tempering process is used to decrease the brittleness

V. TEMPER HOLD: - In this section of cryogenic treatment, hold the material at elevated temperature but below the lower critical temperature. Hold the material for at elevated temperature for 3 to hours to ensure the same temperature in entire material. Holding time depends upon the mass and thickness of material. Some time more than one tempering process is used to obtain the desire properties.

Cryogenic treatment process is the new technique to increase the hardness, toughness, strength and mechanical properties of material more than all same properties increase by convention heat treatment process but cryogenic treatment has one problem means cryogenic treatment is very costly as compared to conventional heat treatment. And conventional treatment has one problem, some amount of austenite retains in heated material and this problem is removed by cryogenic.

5. Machining of metals

Machining process has different types of definition but in short term we can say that machining process is the process by which we remove the excess material from original object by help of different types of machine to obtain the desire shape and size of an object. And this manufactured object can be used in different places to obtain the useful work. When we perform the machining process on any workpiece to remove

the excess material from any object then broad type of tools, machines, equipment, work piece, cutting fluid and other required objects are used. During machining process, some terms arise such as cutting force, heat generation, shear plane, cutting speed, depth of cut, feed rate, metal removal rate, chip velocity, shear velocity, friction between cutting tool and workpiece. All termed used in machining process are important to know before perform the machining operation and these all termed have affect on each other such as when we increase the depth of cut then cutting form also increase , when we increase the rake angle then cutting force decrease etc. In machining process, selection of cutting tool mainly depends upon the hardness of workpiece and second factor is cutting speed.

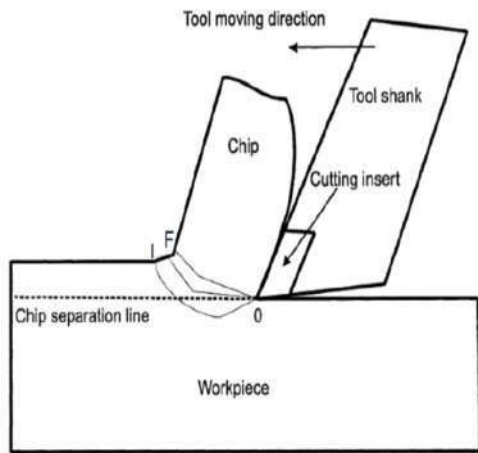


Figure: 1 orthogonal machining

5.1. Some important points

- **CUTTING SPEED:** Cutting speed is motion of cutting tool, cutting speed take place in every machining process. Its unit takes in meter per minute normally.
- **FEED RATE:** Feed rate normally take place in turning operation, motion of cutting tool in one revolution is called feed rate. Its unit occurs millimeter per revolution.
- **DEPTH OF CUT:** Depth of cutting tool in workpiece is called depth of cut. According to how much material is to be remove from workpiece , we set the depth of cut.
- **SHEAR VELOCITY:** Velocity of chip relative to tool face is called shear velocity.
- **METAL REMOVAL RATE:** Amount of material removed per minute is called metal removal rate.
- **RELIEF ANGLE:** Angle between flank of tool and machined surface of workpiece is called relief angle.
- **KNIFE ANGLE:** Angle between face and flank surface of cutting tool is called knife angle of cutting angle.

- **RAKE ANGLE:** Angle between face of tool and line perpendicular to surface of workpiece.

5.2. Types of cutting process

Cutting process mainly two types:

I. Orthogonal cutting

II. Oblique cutting

5.2.1: Orthogonal cutting

In orthogonal cutting, cutting edge of tool always occur perpendicular to the cutting speed of tool and direction of motion of chip always occurs perpendicular to the cutting edge of tool and direction of motion of cutting tool. It is also called two dimensional cutting because in this cutting operation only two components of force act names are thrust force and cutting force.

5.2.2. Oblique cutting

In oblique cutting, cutting edge of tool inclined at acute angle with direction of cutting speed and chip flow direction has also inclined angle with normal to cutting tool edge. Oblique cutting also known as three dimensional cutting because here three type of cutting force take place which are cutting force, thrust force and radial force.

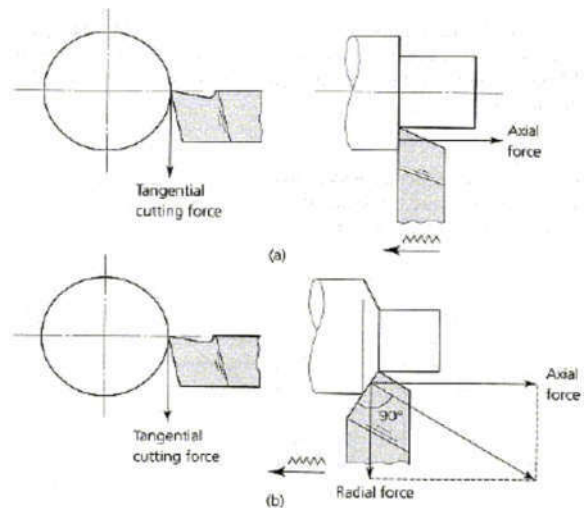


Figure: 2 Oblique cutting

Above figure show the oblique cutting.

5.3. Types of machining proc

- Turning
- Milling
- Boring
- Reaming
- Drilling

5.3.1. Turning operation

Before to describe the turning operation, some point about turning process are needed to know such as head centre, dead centre, tool stool, rotational speed, carriage, tool insert, tool

holder, workpiece, depth of cut, feed rate, cutting speed, thrust force, feed force, rotational speed and hand wheel. Turning operation can be performed by use of lathe machine or CNC machine. Lathe machine operates manually while CNC machine is semi automatic machine or semi manually controlled machine. DEAD CENTRE: Dead centre is a part of lathe and CNC machine in which workpiece holds.

HEAD CENTRE: Head centre is also a part of lathe and CNC machine in which cutting tool holds.

CARRIAGE: Carriage of lathe and CNC machine directs the motion of cutting tool.

TOOL HOLDER: Tool holder holds the cutting tool.

TOOL INSERT: Tool insert is the edge of cutting tool, which is used to remove the excess material from original workpiece.

6. Machining of tool steel

Machining (turning operation) of tool steel is very difficult as compared to machining of common material because hardness of tool steel is very high about from 38HRC to 43HRC therefore selection of tool is also difficult problem because hardness/strength of tool should be higher than hardness/strength of workpiece. Therefore some limited insert tools are used for machining the tool steel such as cubic boron nitride insert tool and diamond insert tool etc. In machining operation several parameters are considered such as cutting speed, cutting edge, cutting fluid and other factors and then we measure the effect of all these parameters on machining of tool steel. In machining process we measure the different parameters like chip morphology, tool wear, roughness and other important factors. In machining of tool steel, researchers found more methodology to machine the tool steel but no one satisfied the requirement of machining properties therefore I decided to find best result of machining process to obtain the desired properties of material then I will perform the machining operation on material before the heat treatment process, after conventional heat treatment process and after cryogenic treatment process then I will compare the all three results obtained before, after the heat treatment and cryogenic treatment process then I will be able to find the best result of machining process. In machining of tool steel, sometime working fluid is used or sometime not used it depends upon the hardness of material, speed of cutting and depth of cutting etc. different losses take place during the machining of tool steel such as frictional loss etc. In this project I focus on roughness, tool wear and chip morphology.

7. Chip morphology

Chip morphology is the study of chip formation means which types of chips form with different machining conditions. The formation of chip depends upon the different factors such as cutting speed, edge of cutting tool, temperature during machining, presence and absence of working fluid and hardness of workpiece etc. during the machining, different types of chips form such as continuous chips, segment chips, serrated chips and continuous chips with buildup edge etc. Normally, continuous chips with buildup edge and continuous band chips form in conventional machining in ductile material

but serrated chips formation mainly influence due to almost every aspect of machining with high speed such as cutting temperature, cutting speed, tool wear and machined surface quality etc. therefore many researchers are trying to investigate the chip formation mechanics with high speed machining by use of numerical values.

8. Results

The experimental result for measuring the roughness of machined surface of workpiece was tabulated in design matrix. These experimental plans were developed for installing the quadratic models of R_a . These results obtained in design matrix was put in a software which is known as design expert. Then machining operation was performed at all values of input variable, and then output values (surface roughness) were measured by use of an appropriate instrument. Here input variables are feed rate and cutting speed, these two variables were tabulated in design matrix. And then turning operation was performed at each condition and then roughness of machined surface was measured by using the roughness tester and then these all values of roughness at several conditions were put into the design expert software at place of response. After putting the input and output values at different conditions simultaneously, ANOVA application installed in design expert is used to analysis of all values then graphs generate, some graphs are 2D and some graphs are 3D. Feed rate and cutting speed are our input variables while surface roughness is our output variable. Two types of heat treatment are performed on workpiece therefore turning operation was done on the workpiece before and after the heat treatment process. Tabulated in design matrix for feed rate and cutting speed do not change before and after the heat treatment process but output values of surface roughness change after and before generate in two dimensional and some graphs generate in three dimensional. By help of these graphs we find out the optimum result of roughness, feed rate and cutting speed. Tool wear also measured before and after the heat treatment at these all tabulated values in design matrix. After performing turning operation without any heat treatment process on rod of tool steel D3, average surface roughness (R_a) were measured by using roughness tester. These results obtained and input values are given in a table simultaneously.

8.1 Residual plots

All the figures given below show the residual plots for surface roughness (R_a)

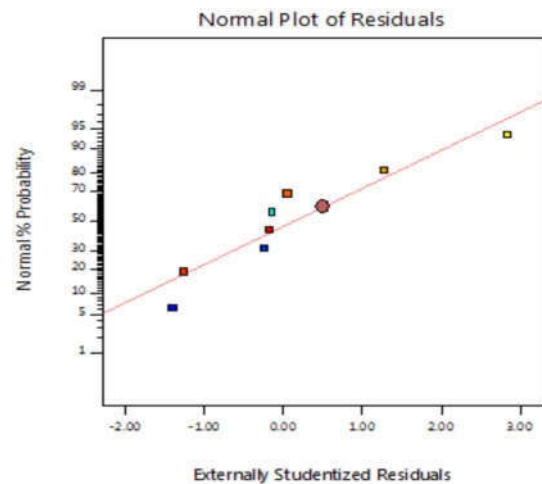


Figure 3 (a)

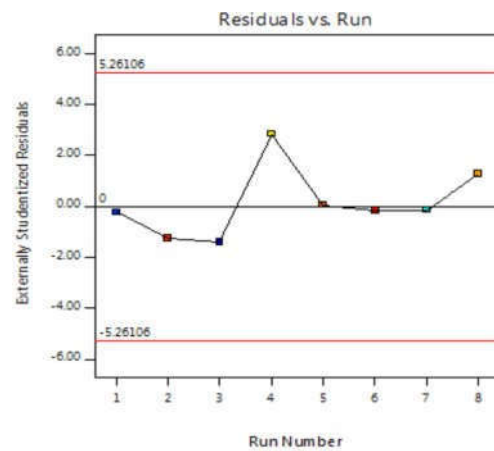


Figure 3 (d)

Figure 3. Residual plots

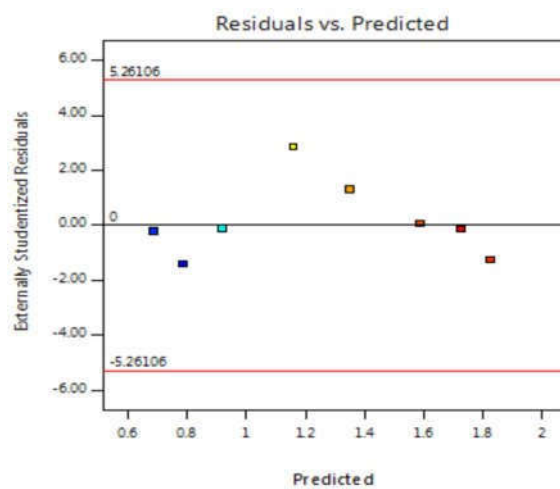


Figure 3 (b)

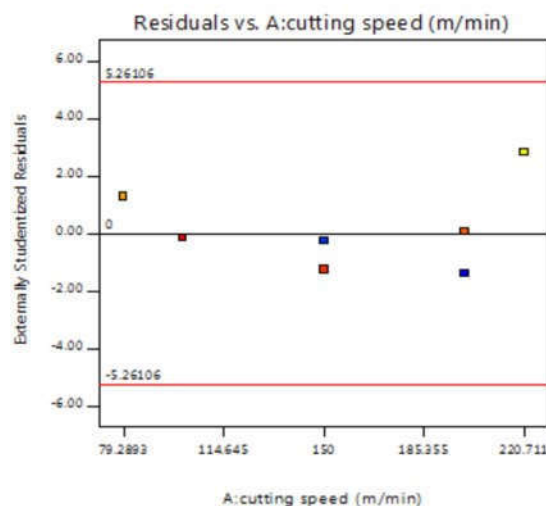


Figure 3 (c)

In normal plot of residual figure 4.1 (a), all points of result are almost near to the straight line therefore this model is an adequate and this plot also shows normal distribution of errors. In plot residual versus predicted figure 4.1 (b), some points are away from the straight. In other language we can say that irregular pattern take place and some errors are find out.

9. CONCLUSION

In above study, impact of certain boundaries (profundity of cut, feed rate and cutting pace) on the chip morphology, wear of hardware, and surface unpleasantness are examination when cryogenic and customary treatment process. Hence finishes of this study are given beneath. Some end which is same all through all the machining activity i.e machining of material with no intensity therapy, machining of cryogenic treated material, and machining of regular intensity treated material. Feed rate and cutting pace both are best boundary during the machining of hardware steel D3 yet feed rate is more viable than cutting velocity when profundity of cut is kept consistent. Normal surface harshness increment with decline in cutting velocity and unpleasantness decline with speed up while normal surface harshness increment with expansion in feed rate and reduction with decline in feed rate when profundity of cut is kept steady.

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