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Comparative Analysis of Annealed AISI D6 and D2 Cold Working Steel

Haseeb Javeed Sheikh[1], Er. Taranveer Singh[2]
[1]Student, Master of Technology, [2]Assistant Professor, Mechanical Engineering, Desh Bhagat University, Mandi Gobindgarh, Punjab, India

Abstract: Mechanical industries where metals are developed various kinds of steel are used for creating tools. This different tool steel has pre measured or defined mechanical attributes. Various effects like thermal, mechanical and other loading effects are applied on this so that tool can bear complex as well as highly aggressive conditions. In this thesis there is comparison is done in two steel tools AISI D2 and D6. As D6 steel has very low machinability behavior in comparison to D2 so it becomes huge difficult work to work with it. In this proposed research there is deep research is done for both the steels by examining their mechanical, micro-structural and other different behavior in both annealed as well as hardened cases.

Different tests like performed on all geared Lathe machine having 8-spindle cutting speed with 24 numbers of feeds. The experiment will be performed on both annealed as well as on the hardened work piece by removing small thickness so that there should be no unwanted material is present on the surface and so have no surface defect. Various independent machine variables are feed, depth of cut and cutting speed for former piece while for hardened work piece one extra attribute is hardness for used hardened steel. Very small time duration test will be performed to get the desired results. Research will be done with the help of statistical techniques to find the most valuable parameters that affect the prime cutting force.

I. INTRODUCTION

A. Development

Steel tool has numerous applications is the machine industry ranging from drawing dies, thread and burnishing as well as forming rolls, mandrels, steel powder must have high mechanical properties and should show at least distortion on the hardening and hence will have high machinability. Various kinds of processes which are used in formation of metals like different types of rolling, various varieties of forging and cold keep drawing need quite high quality with high strength steel [1].

Basically tool steel belongs to a family of carbon. Also all the alloy steels have various distinct properties like hardness, toughness of material, resistance in wear and also resistance of softening at very high temperatures. These tool steels also contains various carbide elements like chromium, molybdenum, vanadium, tungsten and have various combination values. To improve the tool steel at elevated temperatures cobalt as well as nickel are also added. For increasing the hardness of tool steels the basic heat treatment is applied and then it could be utilized for forming, shearing and for cutting metals and as well as for formation of plastics [2].

Figure 1.1: Carbon steel [40]

Main benefits of these steels are high resistivity, good dynamic loading, high thermal shock resistance, high tensile as well as high compression yield strength which are useful for resisting in plastic deformations at localized stress concentration points in the tooling process. So both mechanical and biological properties of the material should be in range so that cost of wear should be minimum to metal forming industry as steel is used in every type of manufacturing sector [1].

Figure 1.2: Steel pieces in rolled form [41]

B. *Classifications Of Tool Steel*

1) *Basic Categories Of Steel*

Tools steels fall into three basic categories:

- Cold work tool steels
- Hot work tool steels
- High-speed tool steels

a) Divisions of the Cold Work Steel

- Air-hardening cold-work steel
- Medium-alloy cold-work steel
- High-carbon or high-chromium cold-work steel
- Oil-hardening cold-work steel

b) Divisions of the Hot Work Steel

- Chromium
- Tungsten
- Molybdenum hot work steels

c) Divisions of the high-speed tool steels

  - Molybdenum
  - Tungsten
  - Intermediate high-speed steels

d) Other Types of tool Steel

- Water-hardening tool Steel
- Shock-resistant tool steel
- Low-carbon tool steel
- Low-alloy special purpose tool steel

Resistance to the corrosion can also be increased by adding vanadium so that chemical properties would change. There are various grades which lower the addition of manganese so that during quenching of water there is very less cracking occurs. Also the oil is also used for quenching the other material [3-10].

2) Types Of Tool Steel Based On The Grades

The various distinct tool steel grades include:

a) Water Hardening
b) Air Hardening
c) D Type
d) Oil Hardening
e) Shock resisting types
f) Hot-Working.

There are number of factors on which selection of tool steel depends like

- Sharp cutting is needed or not.
- Tool has to withstand impact loading of axes or hammers or not.
- Abrasion resistance is considered or not.
- Kind of heat treatment is needed.

C. Explanation of Various Tool Steel Grades

1) *Water Hardening:* Fundamentally it is a high carbon plain-carbon steel and is known as W-Grade tool steel. It is usually could be bought at lower cost and is used for small parts and as well as for small applications. It has a drawback that it could not be used at elevated temperatures. The quite high hardness could be achieved by this steel. As compared to other steel it is quite brittle [8-15]. W-grade steel has quite low hardenability so this type of steel must be subjected to a fast quenching and requires the use of water. This type of steel works nicely for springs and these days have very small applications in the industry. It is assumed that this grade steel should be water quenched and that can further increase warping as well as cracking. The most applications of this grade tool steel are cutting tools as well as knives, reamers, cutlery, embossing and cold heading.
2) *Air Hardening:* This type of tool steel is versatile in natures as it is used for various purposes and is also known as A-Grade tool. As this tool steel has very good chromium content and is characterized by very low distortion in case of heat treatment. This type of still shows high machinability property and has a balance of wear resistance and toughness [12-17]. There are various applications of this tool steel some of which are arbors, cams, embossing, lamination, cold trimming, gages, chipper knives, cold shear knives, woodworking knives, lath center knives, coining, cold swaging, die blending, cold forming and many more.
3) *D Type:* This type of tool steel possesses quite high value of carbon as well as chromium which have range amid 10 to 13 percent and is also known as G-Grade tool. This type of steel is combined to formulate the both abrasion resistance and as well as air hardening properties. This type of steel shows good harness till the temperature not raised to 425 °C. As this steel has good chromium content so it is considered as stainless or semi-stainless. Some of the applications of this type of tool steel are blocks of dies, casting of dies, forging of dies and as well as drawing of dies [24-32]. Out of these tools D2 tool steel is very wear resistant and is also not as tough as lower alloyed steels. It is majorly utilized for the production of shear blades, planer blades and industrial cutting tools and sometimes utilized for knife blades.

Table 1.1: Varieties of A, D and O- Tool Steel

A	A2 – A10	Air hardening, Medium alloys
D	D2 – D7	High carbon, high chromium
O	O1 – O7	Oil hardening, Low carbon

Some of the usual applications of the D-grade steel are paper cutters, coining, cold swagging, cold trimmering, cold shear knives, lathe center knives, blanking, thread roll, wire drawing, gages, cold heading die inserts, wire drawing, file cutting, burnishing tool, rotary slitters, die blending, cold forming and many more [25-28].

There are three categories of tool steed for the purpose of cold work having AISI rank O, A and D. All of these categories have quite high carbon content for high hardness as well as wear resistance but have various composition of alloy for cold working applications. So it affects the hardenability as well as the carbide distributions which could be used in the hardened microstructure.

Out of various kinds of steel the AISI D6 is a high carbon with high chromium value of steel having range of carbon from 2 to 2.50%. This is again processed to get good machinability with lower brittleness with minimizing the carbon content in range of 1 to 1.50%. It is commercially available as AISI D1 to D5 steel. There are several of good steel machinability which is low power consumption, low tool wear, and good surface finishing [2]. All steel mills try to give tool steel in annealed manner. The benefit of it is that the machinist could easily machine the tool steel into a pre machined tool providing machining allowances. Quality of surface as well as performance during machining process could be evaluated by cutting parameters, coolants and tool cutting used [23-32].

4) *Oil Hardening:* Oil hardening tool steel is also known as O-grade tool and is used generally for normal purposes. This tool has quite high abrasion resistance and as well as toughness for a quite high ranges of applications. The various applications of this tool steel contains arbors, thread cutters, collets, cold trimming, gages, die blanking and many more.
5) *Shock Resisting:* Shock resisting tool steel is also known as S-Grade steel and from the name it is cleared that it is used for showing resistance at low and as well as at high temperatures. For this type of toughness the carbon content of this type of tool steel is quite low. So this tool steel possesses low abrasion resistance and so have good impact toughness. This tool steel has various applications resulting battering and boiler shop tool, chisels, chisel hot and cold working, chuck jaws, collets, clutches, cold as well as hot swagging, chipper knives, cold shear as well as hot shearing and many more.
6) *Hot Working:* Hot working tool steel is also famous with the name of H-Grade tool steel and is utilized for cutting material at elevated temperatures. This type of graded tool steel has more strength as well as hardness so that it can handle more pressure at high temperatures. This type of steel has low value of carbon as well as quite high value of additional alloys [35-38]. This type of graded tool steel group is used for cutting as well as shaping the given material at quite high temperatures. H-group tool steel has quite small composition of carbon and due to good amount of carbide value provides quite fare hardness and as well as toughness and wear resistance to the tool. From H1 to H19 series the tool steel contains just 5% of chromium composition. From H20 to H39 group of tool steel contains the tungsten ranges from 9 o 18%. While from H40 to H59 group of tool steel contains only molmolybdenum.

Table 1.2: H-Grade tool steel varieties

H	H 10, H11, h12, H13	Chromium, Molybdenum
	H14, H16, H19, H23	Chromium, Tungsten
	H20, H21, H22, H24, H25, H26	Tungsten
	H15, H41, H42, H43	Molybdenum

There are various applications of this grade tool steel. Some of these are hot trimming and swaging, hot forging and gripping, cores and die castings of Zinc as well as Aluminium, cold heading die castings, hot forging, dummy blocks and hot shear knives and many more [35-39].

D. Processes Involved In Tool Steel Production

There are various types of processes which are used in tool steel production. Some of these are listed here

Figure 1.3: Tool steel product [42]

1) *Electric ARC Furnace (EAF) Melting*

Figure 1.4: Melting of material in furnace [42]

Electric furnace melting is also known as primary melting. It is primarily relied on the melting of metal chips that are received as product of milling processes and as well as suppliers. Usually this melting utilizes remains of various metal processing techniques.

This welding is usually has very high demand due to its low cost of production. For getting more quality as well as good properties there is always some need of extra treatment. The most basic example of this enhancement is the annealing process which is used to restrict and prevent cracking.

This electric furnace process consists of two steps:

a) First one is the melting the scrap quickly in the furnace.
b) Second one is the refining the melted metal in a separate vessel that allows the possibility to process high volumes of metal.

Actually this is required to prevent the contamination of the melt along the process of melting. So there is quite high requirement of controlled conditions.

2) *Electro Slag Refining (ESR):* This process of electroslag refining is also named as electroslag remelting. In the entire process the metal is melted progressively. The outcome ingots possess high surface quality and have very low notable imperfections and faults.

Also this process of refining generates tool steel of high quality and some of the qualities are

a) Better hot workability
b) Good cleanliness
c) Improved ductility
d) Increased fatigue resistance

Yet it is a quite high expensive process the electroslag refining is a good choice to the various advanced applications.

3) *Primary Breakdown:* This type of tool steel needs machinery for the manufacturing process. It can be open die hydraulic press or it can be forging machines. Although the various types of cross sections which could be designed with the primary breakdown process can be available on the cost of the machines. With the machines various kinds of profiles like square, rectangular, hollow and as well as stepped are possible. The maximum length can range from 6 to 12 meters. Moreover the tool steel manufactured with the primary breakdown provides increase in quality, as well as few to no imperfections and good straightness.

4) *Rolling*

Figure 1.5: Rolling of material [42]

These days rolling mills are utilized in a row and those all rows can have more than twenty mills. The process starts when the steel is heated in an induction furnace. Along the induction furnace the walking beam furnaces could also be used for heating the metal. The process of heating the metal could be completed so that there is no loss of carbon and this process where is no loss of carbon is known as decarburization. After heating or melting the metal the next step is hot rolling which is utilized to give the metal its initial shape. Each and every role presses the sheets so that it becomes thinner and it continuous till the desired thickness is achieved. Next step is the cold rolling which is utilized to get the desired the dimensions. This type of rolling technique allows high tolerances to the final material. As the technology is advancing and that is the case with the steel industry also the all process of tool steel process in now automatic. Now rolling process generates the sheets of steel in coils. The total time taken to one coil is nearly 12 minutes.

5) *Hot and Cold Drawing:* Drawing is used for producing various tool steel profiles. With the help of drawing the highest amount of tolerances could be achieved and even with the help of material of smallest size. As this type of tool steel possesses good strength as well as quite low value of ductility and is applicable to just one sing light pass. With this criteria there is very low cracking of material occurs. For multiple passes the hot drawing is possible with a temperature range of 540° C. With the help of there is increased in the strength of the tool steel.
6) *Continuous Casting:* This type of process of tool steel production is used to lower the production cost. After performing casting process the other various kinds of treatment and as well as the processes is utilized to get better properties. Some of these processes include the annealing, hammer forging and as well as rolling.

II. LITERATURE SURVEY

D. Kundalkar et al. [1] in 2016 suggested two ways through which could be used to increase the tooling life. First one author suggested that tooling life could be increased by adding of some good alloy element to the base material. Second one was the performing improvement of the surface properties. It was found that for cold work tooling process the tool life should be high. Authors suggested that if various variables like wear resistance. Premature chipping, cracking as well as deforming parameters would be kept optimum then tool steel would have long life.

M. Nayak et al. [2] in 2015 performed a study on different behavior of AISI D6 steel. Authors focused investigation on both annealed and hardened circumstances. Author exposed D6 to different tough conditions with different loading effects. Authors found that if machining operation is applied to this steel tool then it becomes very hard as this D6 has low machinability feature. Authors performed various mechanical tasks that showed it had good hardness feature and there was increase in tensile strength and very low resistance in case of both annealed and hardened circumstances of steel. It showed surface roughness and prime cutting force was lowered. Authors used carbide tool for performing machining operation on it. Authors also found that the cutting speed had usually very low or say null effect on the surface roughness and prime cutting force in machining of the steel in annealed situation. A. Kraemer et al. [3] in 2015 performed an experiment that showed the sensitivity process of surface of steel AISI D2. Authors found that in the manufacturing process in special case of stamping was usually forced to different cyclic mechanical loading. It includes various forms like erosion, corrosion and worked under these hard conditions. Authors showed that fine and very tiny crack was moved to the larger crack and it was the result of cyclic loading only. As a outcome of it very low quality of product was manufactured and it lead to sometimes complete destruction of the product. Authors found that both the dies as well as tooling were quite costly and their premature destruction could affect the shop floor of a manufacturing industry.

P. P. Sarket et al. [4] in 2014 performed a deep investigation on the failure of a chopper blade which was taken from a steel plant. The used chopper blades had high applications in the chopping machines which were used for cutting trimmed edges of rolled coils into small pieces so that it could be saved from getting converted into scrap. Authors performed various types of investigations like visual, chemical, microstructural with the help of optical electron microscopy and with the help of scanning electroscope (SEM) and as well as with the help of energy dispersive spectroscopy (EDS) and also the hardness measurements.From the chemical investigation it was found that the given tool steel had equivalent properties to D2 grade in AISI notation. It was due to the fact that broken blade had carbide volume fraction which was in the range of ten to fifteen percent which was usually found in D2 tool steel.

Cicek et al. [6] in 2014 demonstrated the deposition of TiBN on AISI D2 cold work tool steel. This phenomenon was used with silicon wafers and the entire set up was analysed with the help of five different tests. It included X-ray diffraction, scanning electron microscopy, micro-hardness test, indentation and last one was the scratch test. From this research it was found that in case of TiB2, TiN and h-BN when used in crystalline forms for coating purpose that would affect the cracks at the boundary of the given mark. It was found that hardness was on maximum level when the flow rate was lowest.

Podgornik et al. [12] in 2012 performed investigation on powder metallurgy high speed steel S390 Microclean and applied deep cryogenic time and temperature parameters with the plasma nitriding and analysed the tribological performance. Under dry sliding circumstances authors put stress on abrasive wear resistances and as well as resistance to galling. Specimens were cut in the shape of discs and rods and then after performing machining and as well as rolling the soft annealed bars were produced.From the results it was found that the both the values of abrasive wear resistance and as well as galling properties of used high speed steel had increased. Authors further concluded that the austenizing temperature range was also significant as with low value of this temperature resulted in high rate of friction and as well as wear. With the use of plasma nitriding the powder metallurgy high speed steel tribological attributes improved with the reduction in austenizing temperature.

Naravade et al. [13] in 2012 performed an investigation of the wearing behavior of D6 tool steel with the cryogenic heat treatment. For performing the experiment authors utilized two distinct temperatures. For shallow cryogenic temperatures analysis temperature was set at -63 °C and for deep cryogenic analysis temperature was set at -185 °C. Author performed time investigations by keeping cryogenic time of 20 and 40 hours for cryogenic temperatures. Authors performed wear testing with the help of a pin on disk where various load and as well as various velocities were applied. From the investigations author found that the value of retained austenite was decreased after performing cryogenic treatment and with this effect there was significant raise in the wear resistance and as well as hardness. Further with increased value of carbide distribution and removal of retained austenite the deep cryogenic treatment showed improvement over shallow treatment in respect to wear resistance and as well as in hardness.

B. Fnides et al. [15] in 2011 performed an investigation on AISI H11 hot work tool steel having hardness value of 50. Authors performed study to find statistical models of cutting forces in hard tuning case of given tool steel. The given tool steel had no tungsten and also had high wear resistance and as well as had zero sensitivity for temperature variations. This type of tool steel had applications for the highly stressed diecasting moulds and helicopter rotor blades, forging dies and had high value of tool life. Further authors machined the tool steel under the dry conditions with the help of mixed ceramic tool which had 70% aluminium oxide and 30% titanium carbide. Three distinct levels of parameters were set at low, medium and at high values. Minitab was used to deduce the mathematical models with the help of multiple linear regression and response surface methodology. Outcomes of the experiment showed that the depth of cut had higher effect in changing the cutting force components.

Amini et al. [19] in 2010 performed an experiment where authors studied the cryogenic treatment effect on the wearing performance of 80CrMo12 5 tool steel. To study the temperature effect on tool steel two distinct temperatures was utilized. First temperature of 80 °C was used as the shallow cryogenic temperature and second temperature was set at 196 °C as the deep cryogenic temperature. Specimens for investigation were cut into the disk shapes with the help of wire electron discharge machining. Further to get uniform and as well as wear surface the specimens were machined and then combined till range was 600 mesh papers and the surface roughness range was 0.4 lm. For performing conventional heat treatment (CHT) the specimens were preheated at two temperatures. After then specimens were quenched in oil to room temperature and then tempered for 3 hours. From the outcomes of the investigation author showed that the retained austenite was decreased and worked effectively in deep cryogenic treatment (DCT) scenario.

A. Ebrahimi et al. [27] in 2009 worked on the machining of a micro alloyed steel and quenched tempered steels having numbers 30MnVS6 and AISI 1045 and AISI 5140 respectively. Authors used various cutting conditions like feed rate in the range of 0.11 to 0.44 mm/rev, cutting speed in the range of 10-250 m/min, hardness in the limit of 245 to 330 BHN with keeping depth of cut constant. Authors showed the machining properties of hardened as well as annealed steel were totally variable had shown various important conditions that could influence the quality of process.

III. PROBLEM FORMULATION

Mechanical industries where metals are developed various kinds of steel are used for creating tools. This different tool steel has pre measured or defined mechanical attributes. Various effects like thermal, mechanical and other loading effects are applied on this so that tool can bear complex as well as highly aggressive conditions. There are three categories of tool steed for the purpose of cold work having AISI rank O, A and D. All of these categories have quite high carbon content for high hardness as well as wear resistance but have various composition of alloy for cold working applications.

In this thesis there is comparison is done in two steel tools AISI D2 and D6. As D6 steel has very low machinability behavior in comparison to D2 so it becomes huge difficult work to deal with it. In this proposed research there is deep research is done for both the steels by examining their mechanical, micro-structural and other different behavior in both annealed as well as hardened cases. The work was carried on Digital Read Out (DRO) Lathe with Model Number Pioneer-175mm Geared Headed with 8-Spindle at Davinder Iron and Steel Co. (J&K).

IV. RESEARCH GAP AND OBJECTIVES

A. Research Gap

After having a comprehensive literature survey, the various research gaps that were identified which are described here :

1) What are the various mechanical characterizations of annealed AISI D6 and D2 cold working steel?
2) What are the machinability behavior of annealed AISI D6 and D2 cold working steel?
3) Which parameters have high impact on the machining of tool?

B. Research Objectives

This research work will be focused to achieve the following objectives

1) To design, study and implement the results of machining of tools.
2) Prime stress is on finding the parameter having high impact on machining of tool

V. RESEARCH METHODOLOGY

A. Research Methodology

The following steps will be performed to complete this research work:-

1) Take AISI D6 and D2 steel tool.
2) Remove the noise present on the surface of these alloys.
3) Perform the machining of these tools
4) Check the parametric values of these tools.
5) Check the accuracy of result obtained from the process.

B. AISI D2 Steel Properties

D2 steel is best known for its hardening properties with very high carbon and chromium tools steel. Further this steel has quite high value of wear and abrasion resistant properties.

D2 steel is treatable by the heat also and shows hardness in the limit of 55-62 Harness Rockwell Scale (HRC) and shows machining properties in the annealing conditions. D2 steel offers very low distortion properties in hardening conditions. D2 has very high chromium content so it shows the low corrosion resisting chemical properties.

Various applications for D2 Steel are:

- Stamping or Forming Dies
- Punches
- Forming Rolls
- Knives, slitters, shear blades
- Tools
- Scrap choppers
- Tyre shredders

1) Thermal Properties of AISI D2

Property	Value
Thermal Conductivity (W/m-K)	20.9

2) Chemical Composition of AISI D2

Element	Content
Carbon, C	1.55 %
Chromium, Cr	11.5 %
Iron, Fe	85.25 %
Molybdenum, Mo	0.90 %
Vanadium, V	0.80 %

3) Mechanical Properties of AISI D2

Density (×1000 kg/m3)	7.695
Compressive strength	411 MPa
Modulus of elasticity	207 GPa
Hardness, Rockwell C	62
Poisson’s ratio	0.27 – 0.30

C. AISI D6 Steel Properties

D6 steel is a high carbon which has more than 12 percent alloy cold work tool steel with value of tungsten. D6 steel has the specific property of resistant to wear as well as abrasion and so behaves as an air hardening alloy steel. It has also high value of chromium content in comparison to other types of steel and so has good hardening values and has high resistance to tempering and so is dimensionally stable. This AISI/SAE D6 steel is primarily utilized for blanking die and for cutting sheets up to width of 2mm thick, paper & plastic blades.

Steel D6 is also suitable for the given applications like

- Blanking tools
- stamping tools,
- embossing tools,
- scraping tools,
- trimming tools,
- woodworking tools,
- drawing tools,
- press tools,
- stone moulds,
- sintered tools,
- machine knives,
- hammer cores,
- ring rollers,
- thread rolling dies,
- plastic moulds.

1) Thermal Properties of AISI D6

Thermal Conductivity (W/m-K)	20.5

2) *Mechanical Properties of AISI D6*

Density (×1000 kg/m3)	7.695
Compressive strength	1320 MPa
Modulus of elasticity	194 GPa
Hardness, Rockwell C	46

3) *Chemical Composition of AISI D6*

Element	Content
Carbon, C	2.05 %
Chromium, Cr	12.5 %
Iron, Fe	83.05 %
Manganese, Mn	0.80 %
Silicon, Si	0.30 %
Tungsten, W	1.3

D. *Machine Used*

The experiments were carried out on an all geared Digital Read Out (DRO) Lathe with Model number Pioneer-175mm Geared Headed with 8-spindle cutting speed ranging upto 1500 rpm and with 24 numbers of feeds is used.

1) *Key Properties of the Machine*

a) Plastic moulds.
b) Motor power consumption is 2 hp
c) Height of the center is 175 mm
d) Width of the bed is 280 mm
e) Available with 8 number of spindles
f) Spindle speed ranges from 54-1500 rpm

VI. RESULTS AND CONCLUSION

A. *Results*

This lab research work intended to find the effects of cryogenic treatment on the wear behavior of both D2 and D6 tool steel. For this purpose, the temperature was used -180 °C as deep cryogenic temperature. The effects of cryogenic temperature (deep), cryogenic time (kept at cryogenic temperature for 30 hr) on the wear behavior of D6 tool steel were studied.

The different combination of heat treatments like hardening (at 1050 °C) for one hour, tempering (at 600°C) for two hours and deep cryogenic treatment (at -180 °C) for 30 hours was done on D2 tool steel. The different combination of heat treatments like hardening (at 980 °C) for one hour, tempering (at 600°C) for two hours and deep cryogenic treatment (at -180 °C) for 30 hours was done on D6 tool steel. Wear test were performed utilizing pin-on-disc wear tester to which two different normal loads (3.2 Kg and 5.3 Kg) and two different velocities (1.5 m/s and 2.5 m/s) were applied. Hardness of specimens was measured by using Rockwell Hardness tester. The incidence of microstructure characterization of quenched D2 and D6 cold work tool steel was done using non-destructive electromagnetic techniques.

1) *Microhardness Measurement:* A Vickers hardness testing machine capable of applying a predetermined force with the required range of test forces, an indenter and measuring device was used to measure the surface hardness of the test piece. The test piece of Ø 30 × 40 mm cylindrical work pieces was faced on the flat face with CBN tool (cutting condition 700 rpm; DOC = 0.1 mm; feed 0.1 mm/rev.) to generate a surface. The Rockwell hardness measured on the surface of the D2 steel according to BIS was 58.7HRC and on the surface of the D6 steel according to BIS was 40.2 HRC. The Vickers hardness test was conducted in accordance to BIS. The approximate hardness in case of D2 varies amid 53 to 64 HRC that suggests that there is increasing of hardness on the surface as a result of metallurgical alteration due to the cutting forces and temperature. This hardened surface further improves the wear and abrasion resistance of the tool surface and prevents any hard particles usually leaving deep scratches and causing damage to the form rolls.

The approximate hardness in D6 scenario varies amid 54 to 65 HRC which hints that there is increase of hardness on the surface as a result of metallurgical alteration due to the cutting forces and temperature.

Table 6.1: Microhardness of the steel

S. No.	D2		D6	
	9800 N for 15 Sec	4900N for 15 Sec	9800 N for 15 Sec	4900N for 15 Sec
1	780	820	750	780
2	790	830	770	795
3	773	815	760	778

2) *Hardenability Test:* The hardness measured on the surface after hardening and tempering of the D2 steel according to standard was 57.3 HRC of the D6 steel 60.3 HRC. To measure the hardness of the steel at the core, step turning procedure was adopted. The hardness values were taken in each step turned at 5 mm below the surfaces generated. It was found that there was hardly any major variation of hardness at the surface of Ø 22 mm and at Ø 15 mm core of the cylinder in both cases of D2 and D6. The hardness varied from 59.3 HRC at the surface to 57.8 HRC at the core for D2 steel and from 57.3 HRC at the surface to 56.1 HRC at the core for D6 steel. This only suggested that both the material is very much susceptible to through hardening and possesses good hardenability property.
3) *Optical Microscopic Test:* Optical microscopic test was conducted with an inverted optical microscope as per ASME standard. Total two specimens were sectioned from hardened as well as non-hardened lengths. Specimens were taken from before and after treatment. Then the specimens were polished with emery paper and then polished with cloth to get shining surface. The specimens were cleaned and washed by detergent powder and water. After drying by using hot air and then etching was conducted and then specimens were put under the investigation by SEM microscope. From the scanning electron microscope images showed that there is dispersion of small and large particles in both of the conditions of D2 as well as D6.

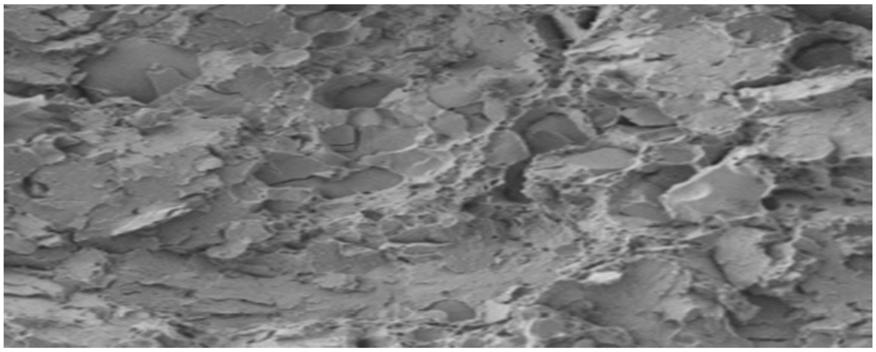

Figure 6.1: SEM images of fracture surfaces of D2 with 1500 times magnification

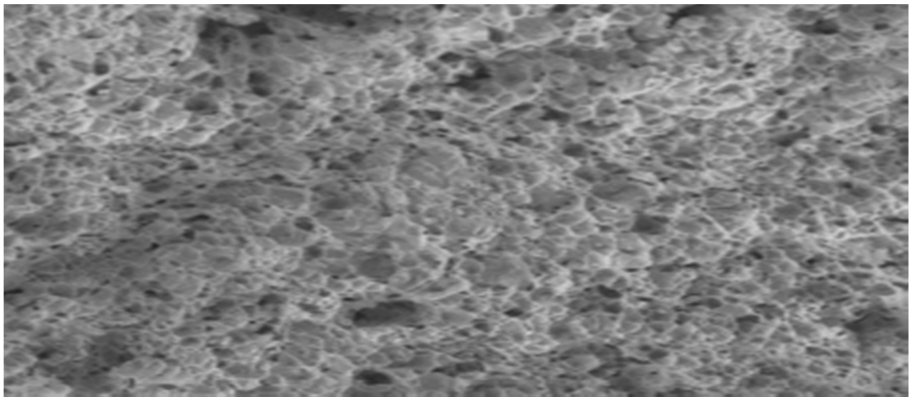

Figure 6.2: SEM images of fracture surfaces of D6 with 1500 times magnification

From the figure 6.1 and 6.2 it is found that the D2 is more wear resistance in comparison to D6 steel and this is due to the fact that hardness is remained steady with increase in stress.

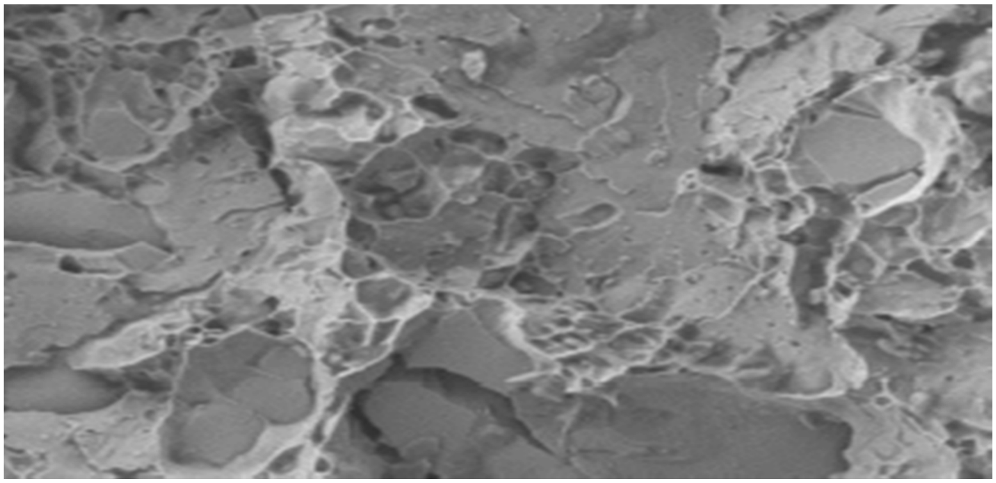

Figure 6.3: SEM images of fracture surfaces of D2 with 3500 times magnification

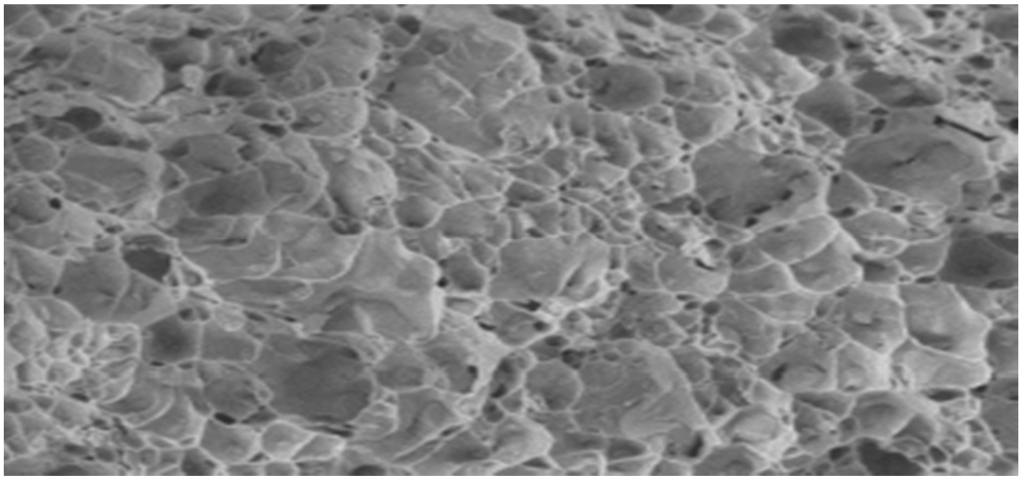

Figure 6.4: SEM images of fracture surfaces of D6 with 3500 times magnification

From the figures 6.3 and 6.4 it is found that the D2 is more wear resistance in comparison to D6 steel and this is due to the fact that hardness is remained steady with increase in stress.

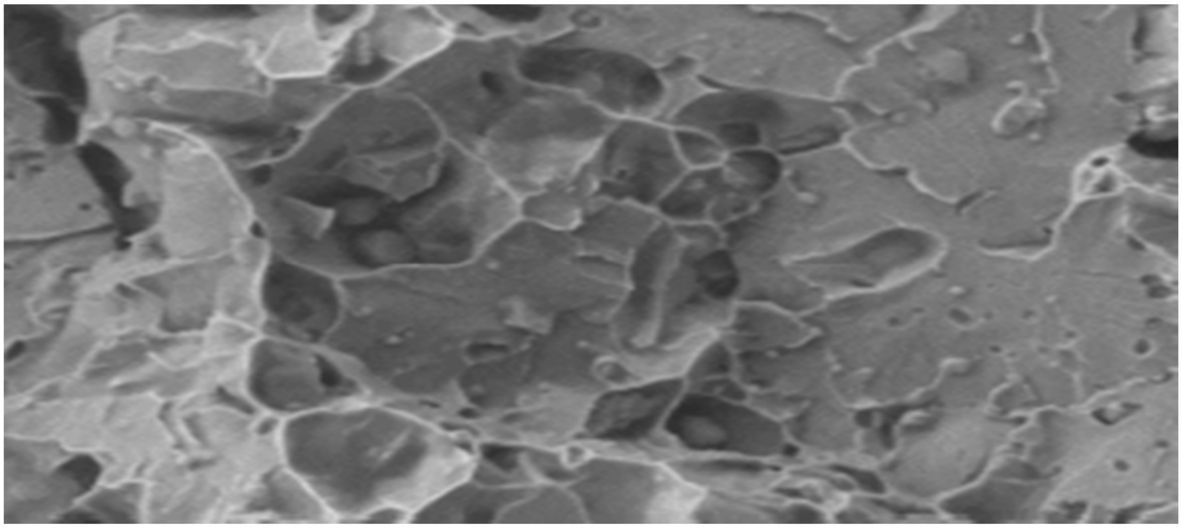

Figure 6.5: SEM images of fracture surfaces of D2 with 7500 times magnification

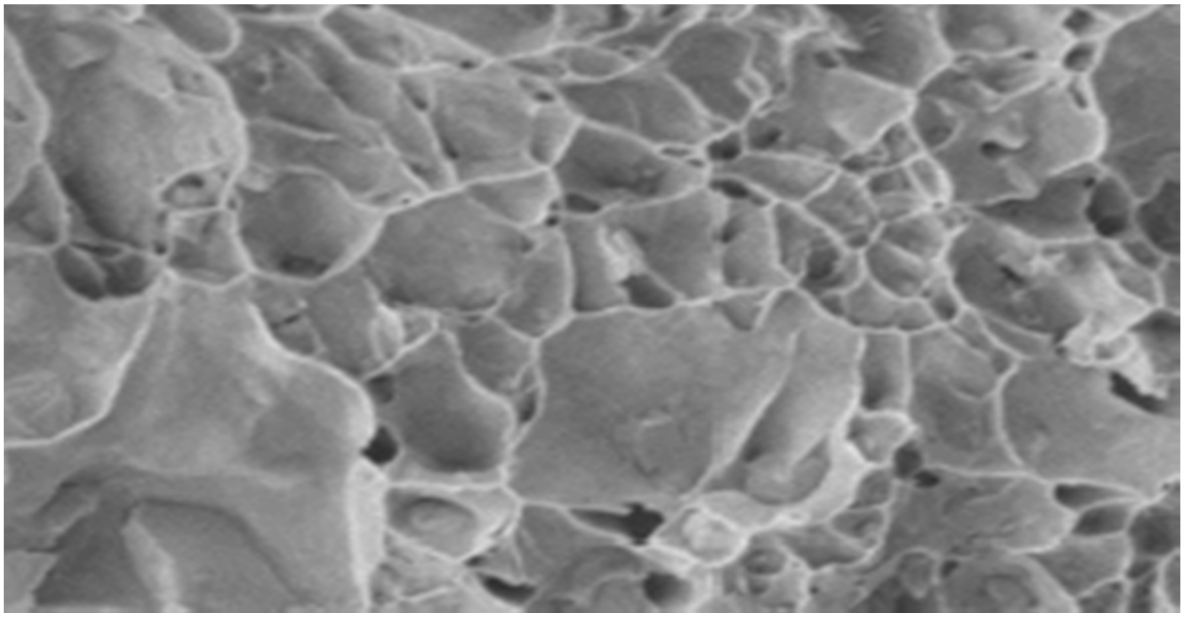

Figure 6.6: SEM images of fracture surfaces of D6 with 7500 times magnification

Again from the figure 6.5 and 6.6 it is found that the D2 is more wear resistance in comparison to D6 steel and this is due to the fact that hardness is remained steady with increase in stress.

4) *Tensile Test:* Tensile test was performed according to BIS standard on a 50-tonne UTM. Tool steel bars of both steel were machined to a smooth gage section in the center and a larger shoulder on each end for tensile tests. For each test condition two samples were tested. The tensile strength of tool steel is directly related to its hardness. The hardness of the tensile specimen was measured to be 58 HRC and 42 HRC for D2 and D6 steel respectively. The tensile strength of the hardened steel improved phenomenally and the ductility decreased in both cases of D2 and D6 steel. As the compressive yield strength parameter is quite significant but when the cracks start appearing in the tool under investigation then tensile strength and as well as ductility also play a big role. It is all due to increase in the value of tension.

Table 6.2: Tensile test data

Parameters	D2		D6	
	Specimen 1 (Annealed)	Specimen 2 (Hardened and Tempered)	Specimen 1 (Annealed)	Specimen 2 (Hardened and Tempered)
Hardness Measured	95.6 HRB	57 HRC	98.6 HRB	58HRC
Diameter (mm)	10.01	10.03	10.00	10.02
Area	78.90	82.9	78.50	81.67
Gauge length	50.00	50.00	50.00	50.00
Elongated length (mm)	54.25	52.31	53.70	50.58
Tensile strength (mm)	700.21	2000.35	687.90	1855.03
Yield stress (N/mm2)	459.37	NA	445.86	NA
Elongation %	8.25	2.27	7.40	1.16

5) *Charpy (V-Notch) Test:* This test is conducted to find the toughness of the material. This test specifies the Charpy impact (V-notch) technique to find the impact value of the tested steel and was done as per BIS standard. Six standard steel specimens or three sets for the given experiment were machined from annealed steel bar. Two sets of the steel specimens were hardened and one set was tempered twice and another set was tempered thrice and the average Rockwell hardness for D2 was measured to be 58 ± 5 HRC and then subjected to Charpy impact test and for D6 was measured to be 59 ± 5 HRC. The test piece was fixed squarely against the support and the plane on symmetry of the notch within 0.5 mm of the plane midway amid them. Further the piece was made to strike with the help of striker in the plane of the symmetry of the notch and on the side opposite to the notch. The outcomes of the experiment indicated that the D6 material has a low resistance to impact in both annealed and hardened condition. While the outcomes in case of D2 material indicated that it has a high resistance to impact in both annealed and hardened condition.

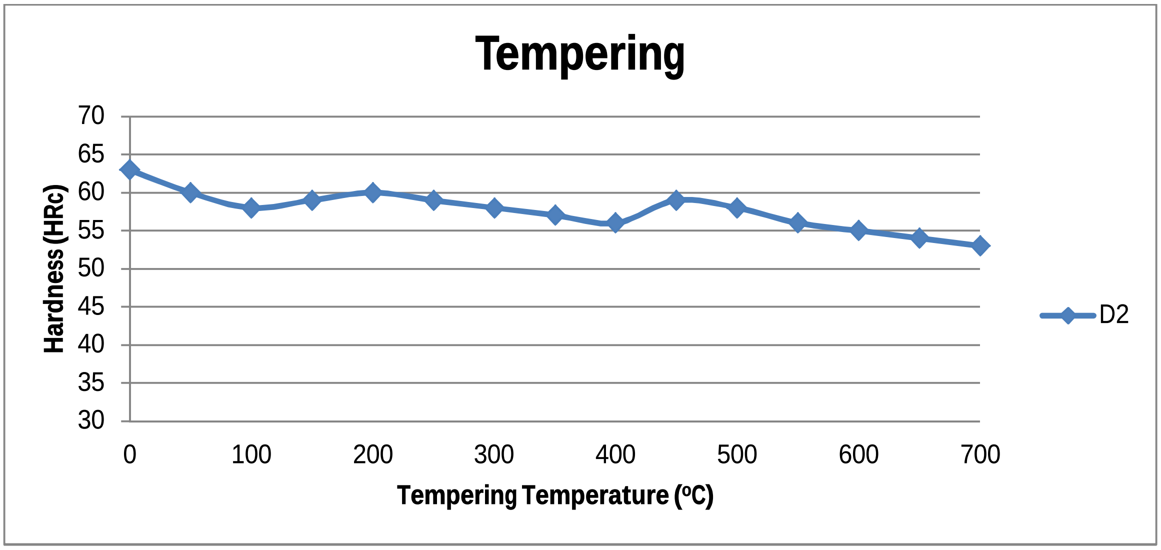

Figure 6.7: Tempering hardness graph of AISI D2 steel

Above figure show tempering behavior of AISI D2 steel. On tempering the hardness start decreasing with raise in temperature. At the two positions the hardness increased with raise in temperature.

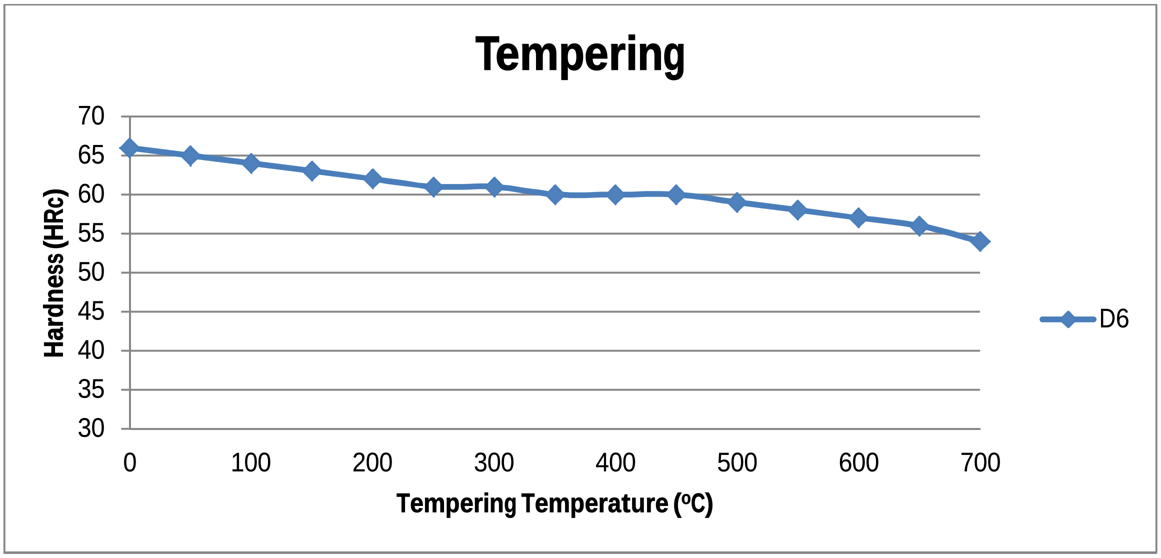

Figure 6.8: Tempering hardness graph of AISI D6 steel

Above figure show tempering behavior of AISI D6 steel. On tempering the hardness starts continuously decreasing with raise in temperature.

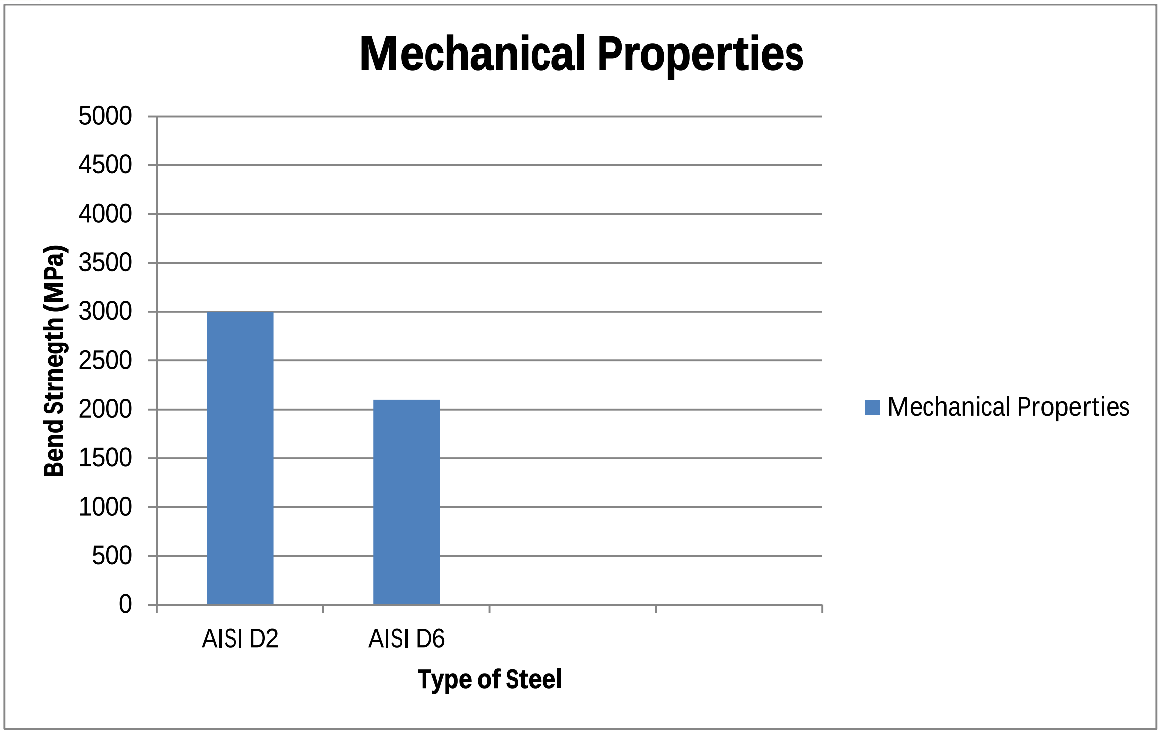

Figure 6.9: Mechanical properties of AISI D2 and AISI D6 steel

From the graph it is clear that the bend strength of AISI D2 steel is more in comparison to AISI D6 steel. It is due to the reason that D2 shows more elastic behavior in contrast to D6 steel.

B. Conclusion

The higher ductility and toughness of “D6” over “D2” tool steels were due to the high content of molybdenum and Cr. While the higher yield tensile strength as well as ultimate tensile strength (UTS) of “D2” compared to “D6” tool steels were due to the increased content of tungsten as well as manganese (Mn). The “D6” steel behavior under monotonic loading showed particularly high hardening and substantially low softening due to the high content of Mo and Cr. The range of hardness for “D2” and “D6” steels was 56–58 and 60–62 HRC, respectively.

Further it has been found that D2 steel has more wear resistance in comparison to D6 steel. In case of Toughness D6 steel is stronger in contrast to D6 steel. Also D6 is more stable in the heat treatment as compared to the D2 steel.

C. Future Work

In the future work D2 and D6 steel will be more explored by taking other various temperatures for annealing and hardening. Also other steel will also be compared in comparison against these steels. Steel with various types of composition in pure or in impure could also be tested for getting various outcomes.

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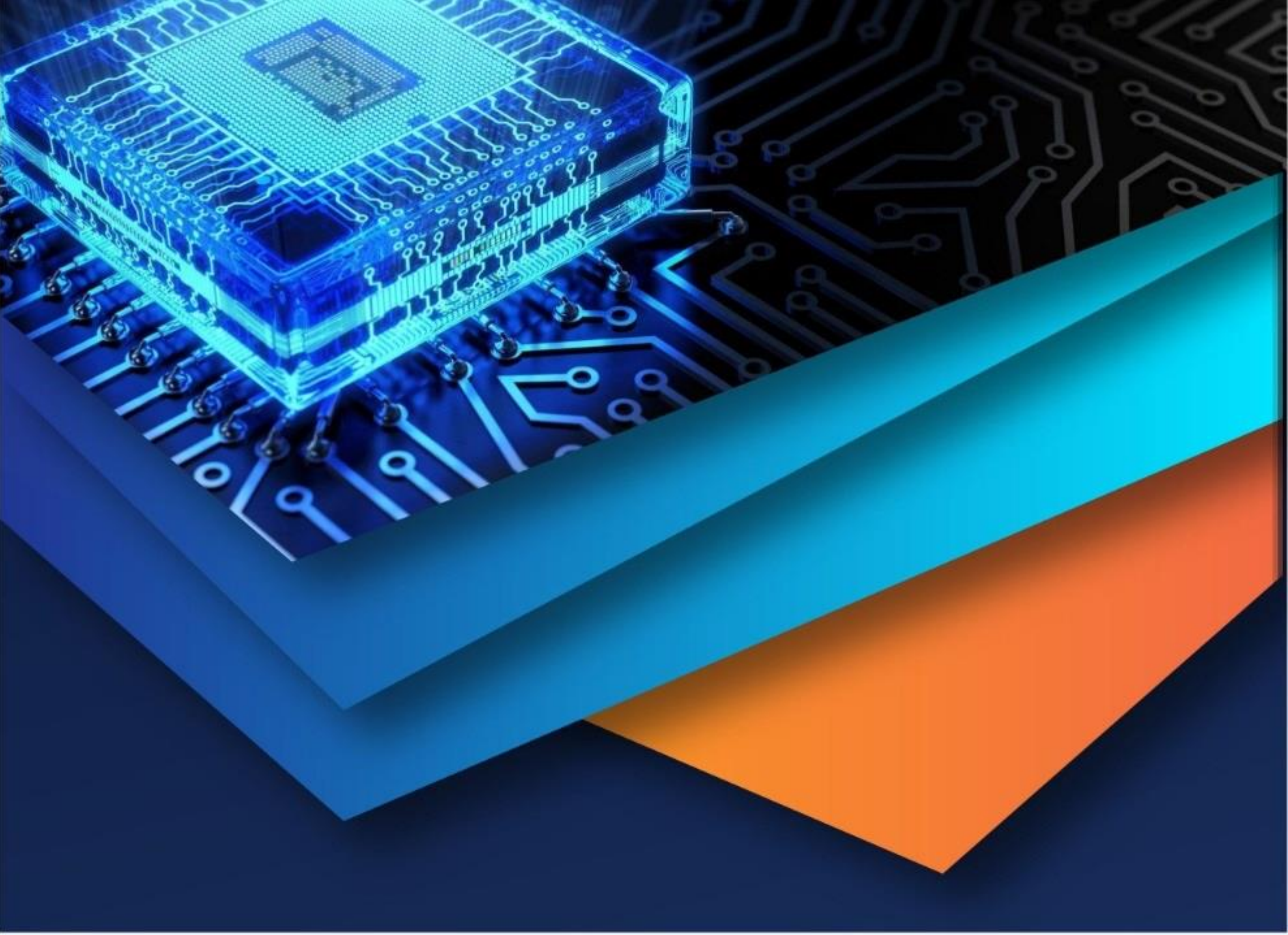

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