

“Effect of heat treatment on the mechanical properties of SS316 steel”

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Abstract

Effect of heat treatment on the mechanical properties of SS316 steel. The main objective of this project is to investigate the effect of heat treatment and notch size on impact strength of SS316 material. Three types of heat treatment were performed in this project which are annealing, normalizing and quenching. During annealing process, the specimens were heated at 900°C and soaked for half hour in the furnace. The specimens were then quenched in a medium of water and open air, respectively. After the heat treatment process completed, Rockwell hardness test and Charpy impact test were performed. The results collected from the Rockwell hardness test and Charpy impact test on the samples after annealing, normalizing and quenching were compared and analysed. The fractured surfaces of the samples were also been examined by using Inverted Microscope. It was observed that different heat treatment processes gave different hardness value and impact property to the steel. The specimen with the highest hardness was found in samples quenched in water. Also the effect of notch size on impact strength was studied.

Keywords: Quenching, Heat treatment, Notch, Surface, Microscope

1. INTRODUCTION

Heat treatment is a process that involves a combination of time-controlled heating and cooling operations of metal without changing the product shape that will produce desired mechanical properties and to observe the microstructure after heat treatment. Heat treatment is used to improve the mechanical properties of the metal alloys. Basically, the product performance will improve when the strength of material increased. It can be divided into three main processes namely annealing, quenching and normalizing. In general, the procedure of heat treatment process consists of three stages. First stage is heating the material. Second, hold the temperature for a period of time and third, cool down the metal to room temperature.

The treatment of SS316 steel with heat can significantly change the mechanical properties, such as ductility, hardness and strength. Heat treatment of steel slightly affects other properties such as its ability to conduct heat and electricity as well. A variety of methods exist for treating steel with heat. The carbon and manganese content in steel make quenching and normalizing the most common method of heat treatment for this type of steel. This process generally involves repeatedly heating the steel and cooling it rapidly by quenching it in a liquid such as oil or water. The temperature and time of this process allows the manufacturer to precisely control the final properties of the steel.

Austenitic stainless steels (ASS 316) owing to their excellent high temperature mechanical properties, find wide applications as piping and heat exchanger tubes materials in steam generating plants and as cladding and structural materials in liquid metal cooled fast breeder reactors. Austenitic stainless steels are susceptible to sensitization when they are exposed in the temperature range 773K to 1123K for sufficient length of time. The principal effect is the precipitation of type carbides and the consequent depletion of chromium in the regions adjacent to grain boundaries to levels below that required for protection against corrosion. In addition to the loss of corrosion resistance, carbide precipitation at grain boundaries also influences the mechanical properties. Recently carried out a detailed study on the effects of ageing in the sensitization temperature range (823-1123 K) on the microstructure and tensile and impact properties of a Type 316 stainless steel.

1.1 Objective :

1. To investigate effect of heat treatment on impact strength of material.
2. To investigate the effect of notch size on impact strength of material.
3. To correlate the hardness and impact strength of material.

1.2 Problem statement:

Grade 316 is the standard molybdenum-bearing grade, second in importance to 304 amongst the austenitic stainless steels. The molybdenum gives 316 better overall corrosion resistant properties than Grade 304, particularly higher resistance to pitting and crevice corrosion in chloride environments. It has excellent forming and welding characteristics. It is readily brake or roll formed into a variety of parts for applications in the industrial, architectural, and transportation fields. Grade 316 also has outstanding welding characteristics. Post-weld annealing is not required when welding thin sections. Grade 316L, the low carbon version of 316 and is immune from sensitisation (grain boundary carbide precipitation). Thus it is extensively used in heavy gauge welded components (over about 6mm). Grade 316H, with its higher carbon content has application at elevated temperatures, as does stabilised grade 316Ti. Austenitic stainless steels 316 are widely used for manufacturing of various steam generation and other structural components due to their good mechanical and corrosion resistance properties. However, the need for superior properties in specific applications (e.g. steam generators, mixer blades, etc.) led to wide researches on the performance improvement of these steels. Heat treatment was recommended as one of the best ways to this regard hence the effects of austenitizing temperature and time, and tempering temperature on the microstructure, and impact strength properties of 316 steel need to be studied. The fracture toughness plays a significant role in the structural integrity assessment of reactor pressure vessels (RPVs) in service temperature. The Charpy V-notch (CVN) impact test is used to estimate fracture toughness (KIC or KJIC) indirectly since universal fracture toughness tests are costly, sophisticated and frequently invalid.

2. LITERATURE REVIEW

J NAYAK, K R UDUPA, K R HEBBAR and H V S NAYAK [2004] Weldments of AISI grade 316 stainless steel, having a ferrite content of 4–6% and a variety of nitrogen concentrations were prepared using a modified element implant technique. Charpy impact specimens prepared from these weldments were subjected to a variety of aging treatments. Impact toughness decreases with aging time at all aging temperatures. Nitrogen is found to be beneficial to toughness. An empirical relation connecting the aging temperature, aging time and nitrogen content with toughness has been developed which can be used to estimate the time for embrittlement.[1]

Minakshi Vaghani, Dr. S.A. Vasanwala, Dr. A.K. Desai [2014] Stainless steels have not traditionally been widely used as structural materials in building and civil engineering. Where the steels have been used for this purpose there has been some other imperative driving the design, usually corrosion resistance or architectural requirements rather than the inherent structural properties of the steel. The primary reason for this low use in structural applications is usually the perceived and actual cost of stainless steel as a material. Developments over the last 10 years, both in available materials and attitudes to durability, are now offering a new opportunity for stainless steels to be considered as primary structural materials. This paper introduces stainless steel alloys and briefly discusses the important properties and commercial aspects of these alloys relevant to structural designers. The paper also considers recent developments, particularly with respect to available alloys and considers obstacles to the wider use of stainless steels in structural engineering that are related to both supply chain costs and efficiency of design. [2]

P.Elango [2014] SS316 stainless steels have been widely used in highly corrosive environments for power generation, chemical, fertilizer, marine, food, oil and gas industries and petrochemical reactors. These materials are well known for their good corrosion resistance and mechanical properties like strength etc. However, because of its low hardness and wear resistance their applications are greatly limited. The Austenitic steel has an Austenitic structure is stable at ambient temperature and characterized by the presence of chromium and nickel and low carbon content Austenitic steels are used in various aggressive environments and at high and low temperatures. The most common heat treatment for all types of austenitic steel is solution annealing. Research is going on over years to reduce the wear either in the form of using a new wear resistant material or by improving the wear resistance of the existing material by addition of any wear resistant alloying element etc. In this paper a study has been made to review few of the methods of improve the properties like wear, corrosion and hardness on austenitic stainless steel SS316. [3]

R. G. THOMAS AND D. YAPP [2015]. The transformation behavior of a Type 316 stainless steel weld metal containing ~ 5% delta ferrite has been studied after aging for 0.1 to 1000 hours in the temperature range 538 C to 900 C (1000 to 1652 F). The extent of the δ -ferrite transformation was followed magnetically, and it was found that the rate of transformation was extremely rapid at temperatures over 750 C (1382 F), e.g. after 10 hours at 800 C (1472 F) the transformation was complete. However, at lower temperatures the rate of transformation was much slower with only ~ 60% transformation after 1000 hours at 600 C (1112 F). All the results could be fitted to classical transformation equations from which it is possible to predict transformation behavior for long lines at power plant service temperatures. Tensile, stress relaxation and room temperature impact toughness properties have also been determined. It is suggested that tensile properties on aging were influenced by two independent processes. The weld metal was initially softened due to annealing of the strain hardened as-welded structure which caused an initial fall in proof stress. However, subsequent aging caused precipitation processes to occur which caused the work hardening rate and consequently ultimate tensile strength to increase. Impact properties also showed an initial rise on aging which it is proposed is associated with the δ -ferrite to austenite transformation. [4]

Noor Mazni Ismail, Nurul Aida Amir Khatif, Mohamad Aliff Kamil Awang Kecik, Mohd Ali Hanafiah Shaharudin[2016]. This paper covers the effect of heat treatment on the mechanical properties of medium carbon steel. The main objective of this project is to investigate the hardness and impact properties of medium carbon steel treated at different heat treatment processes. Three types of heat treatment were performed in this project which are annealing, quenching and tempering. During annealing process, the specimens were heated at 900oC and soaked for 1 hour in the furnace. The specimens were then quenched in a medium of water and open air, respectively. The treatment was followed by tempering processes which were done at 300oC, 450oC, and 600oC with a soaking time of 2 hours for each temperature. After the heat treatment process completed, Rockwell hardness test and Charpy impact test were performed. The results collected from the Rockwell hardness test and Charpy impact test on the samples after quenching and tempering were compared and analysed. The fractured surfaces of the samples were also been examined by using Scanning Electron Microscope. It was observed that different heat treatment processes gave different hardness value and impact property to the steel. The specimen with the highest hardness was found in samples quenched in water. Besides, the microstructure obtained after tempering provided a good combination of mechanical properties due to the process reduce brittleness by increasing ductility and toughness.[5]

Kudzanai Mukahiwa[2016] The environmentally-assisted fatigue crack growth behaviour of austenitic stainless steels in deoxygenated high temperature water at low strain rates has been reported to be greatly affected by the sulphur (S) content of the specimen, with high S specimens exhibiting significant reduced crack growth rates (retardation) when compared to low S specimens. To further the understanding of the mechanistic behaviour, fatigue crack growth experiments have been performed on high and low Sulphur Type 316 austenitic stainless steel specimens tested in high temperature water and evaluated via microstructural characterization techniques. At high strain rates the enhanced crack growth for both specimens appeared to be crystallographic and associated with slip localization. Furthermore, matching fracture surface analysis indicated discrepancy of the slip steps and micro-cleavage cracks between the matching surfaces, suggesting that slip steps and micro-cleavage cracking occurred after the crack-tip had advanced. It was also postulated that their formation may involve cathodically-produced hydrogen and shear deformation on the fracture surface. However, when the loading frequency was decreased, the high S specimens retarded the crack growth and the path was no longer crystallographic.

Significant differences in the crack-tip opening displacements were observed in both materials, with blunt crack-tips in the high sulphur specimen and sharp tips in the low sulphur specimen when the strain rate was low. EBSD analysis at the crack-tips of both specimens showed that the strain was more localised at the crack-tip of the low Sulphur specimen whilst the strain ahead of the high Sulphur specimen was more homogenous. It is thus postulated that retardation occurs when slip localization is no longer the dominant factor. The localized deformation during enhancement is believed to have been caused by hydrogen enhanced localized plasticity (HELP) which causes the crack-tip to sharpen. The diffused strain distribution during crack growth retardation is believed to have been caused by hydrogen enhanced creep (HEC) which causes the crack-tip to blunt. It is also believed that both enhancement and retardation mechanisms are associated with contrasting effects deriving from hydrogen enhanced plasticity. Oxide induced crack closure was excluded as a mechanism responsible for retardation of fatigue crack growth when the stress ratio is high. Effects of hydrogen induced α' and ϵ marten site phases on oxidation behavior of austenitic stainless steels in deoxygenated high temperature water have also been studied. Microstructural characterization shows that hydrogen induced α' marten site enhances oxidation of austenitic stainless steels in deoxygenated high temperature water. The implications of this finding on environmentally assisted cracking of austenitic stainless steels in deoxygenated high temperature water is discussed. [6]

Le Thanh Hung Nguyen , Jae-Sik Hwang , Myung-Sung Kim, Jeong-Hyeon Kim, Seul-Kee Kim and Jae-Myung Lee [2019] 316 stainless steel is a promising material candidate for a hydrogen containment system. However, when in contact with hydrogen, the material could be degraded by hydrogen embrittlement (HE). Moreover, the mechanism and the effect of HE on 316 stainless steel have not been clearly studied. This study investigated the effect of hydrogen exposure on the impact toughness of 316L stainless steel to understand the relation between hydrogen charging time and fracture toughness at ambient and cryogenic temperatures. In this study, 316 stainless steel specimens were exposed to hydrogen in different durations. Charpy V-notch (CVN) impact tests were conducted at ambient and low temperatures to study the effect of HE on the impact properties and fracture toughness of 316L stainless steel under the tested temperatures. Hydrogen analysis and scanning electron microscopy (SEM) were conducted to find the effect of charging time on the hydrogen concentration and surface morphology, respectively. The result indicated that exposure to hydrogen decreased the absorbed energy and ductility of 316L stainless steel at all tested temperatures but not much difference was found among the pre-charging times. Another academic insight is that low temperatures diminished the absorbed energy by lowering the ductility of 316L stainless steel. [7]

3. Methodology of project

3.1. Formation of Process chart

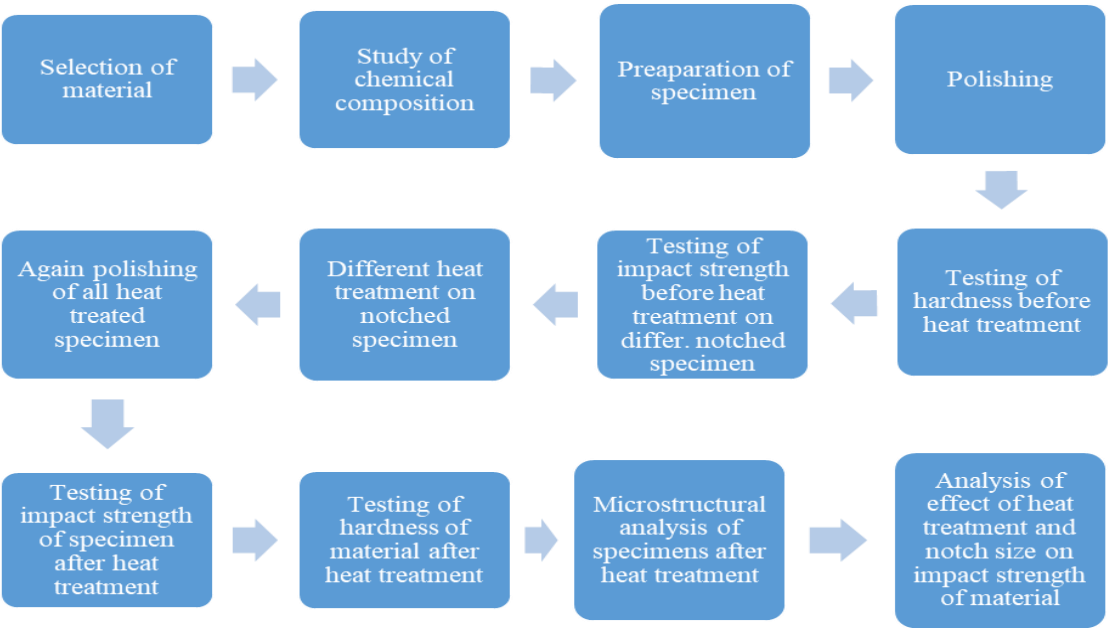


Fig 1 .Implementation of process chart

3.2 Selection of material.

SS316 is the austenitic stainless steel which is one of the widely used steel in various applications like Chemical and Petrochemical Processing-Pressure vessels, tanks, heat exchangers, piping systems, flanges, valves and pumps. Hence we have selected these material for our investigation purpose.

Alloy 316/316L is a chromium-nickel-molybdenum austenitic stainless steel developed to provide improved corrosion resistance to alloy 304/304L in moderately corrosive environments. It is often utilized in process streams containing chlorides or halides.



Fig.2 STAINLESS STEEL 316

3.3 Study of its chemical composition.

Weight % (all values are maximum unless a range is otherwise indicated)

Table -1 chemical composition of ss316 material

Element	316
Chromium	16.0 min to 18.0 max
Nickel	10. min to 14.0 max
Molybdenum	2 min to 3 max
Carbon	0.08
Manganese	2.00
Phosphur	0.045
Sulphur	0.03
Silicon	0.75
Nitrogen	0.1
Iron	Balance

Austenitic stainless steel alloying elements Stainless steel are widely used in different environments due to the fact that their properties can be modified by addition of different alloying elements. The alloys are usually added to stabilise the microstructure, improve strength or corrosion properties. A brief overview of their effect is given below.

Chromium: All stainless steels have Cr content above 12-13 wt %. With increasing Cr content, the main effect of Cr is to improve corrosion resistance and stabilise the ferrite phase

Nickel: Nickel is an austenite stabiliser that gives stainless steels strength, ductility and toughness at high and low temperatures. It also improves the corrosion resistance of stainless steel in acidic environments. Carbon is an austenite stabiliser that improves mechanical strength, however, it is generally undesirable in austenitic stainless steels due to the fact that it has a high thermodynamic affinity for Cr. Because of the high affinity of chromium, carbon causes the formation of chromium carbides at grain boundaries when a supersaturation state in austenite is reached and diffusion is fast enough for segregation of Cr and C to occur. This typically happens at temperature between 1123 K to 723 K when the stainless steel is slowly cooled. The chromium carbides usually precipitate at grain boundaries leaving chromium depleted zones within the vicinity of boundaries. If the chromium is depleted below 12-13 wt%, the depleted zone becomes susceptible to corrosion. Furthermore in Ni containing alloys Cr retards the γ to α' marten site phase transformation making it easier to retain austenite. Therefore the Cr depleted zone becomes susceptible to martensitic phase transformation when chromium carbides are formed. This is supported by TEM characterisation of sensitised austenitic stainless by Butler et al. that showed that marten site was formed at or near sensitised grain boundaries.

Molybdenum: Improves corrosion resistance of stainless steels to uniform and localised corrosion. It also stabilises the ferrite microstructure and improves mechanical strength.

Nitrogen: is an austenite stabilizer that increases mechanical strength and corrosion resistance. Typically added as an alternative to carbon to increase yield strength and reduce the propensity of chromium carbides formation at grain boundaries.

Sulphur and Manganese: In some grades, S is added to improve the machining behaviour of steels. It is also retained in stainless steel because of the inefficiency of melt processing and it is often considered as an undesired element. In fact, S has low solubility in steel, and in Mn containing steel S mainly exists as manganese sulphide inclusions (MnS). These MnS inclusions are soluble in water and can increase the material’s susceptibility to pitting and localized corrosion. Manganese is added during steelmaking operation to segregate S in the form of MnS inclusions, which are more thermodynamically stable than FeS inclusions. In fact, FeS is a low melting point second phase, which forms at grain boundaries and would promote cracking during high-temperature hot-rolling.

3.4. Preparation of specimen of specific dimension.

Specimen of 12 equal sizes were prepared each with dimension of 50mm*10mm*10mm. After that the specimen were provided with the notch by wire cutting method from which 4 specimen were provided with notch of 30° and 4 specimen were provided with notch of 45° and 4 specimen were provided with the notch of 60°.



Fig.3 Stainless steel 316 with notch.

3.5 Polishing of specimen.

All the specimen of SS316 material were polish with the help of polish paper and were given a quite good surface finish.

3.6 Testing of hardness before heat treatment.

Hardness of material was tested with the Rockwell hardness tester before heat treatment of specimen.

3.7 Testing of impact strength of material with different notches before heat treatment.

Impact strength of specimen with notch angle 30°, 45° and 60° were tested individually with charpy impact tester.

3.8 Different heat treatment on remaining specimen.

Nine specimens were kept in box furnace and were heated up to its recrystallization temperature and different cooling techniques were used for different heat treatment process.

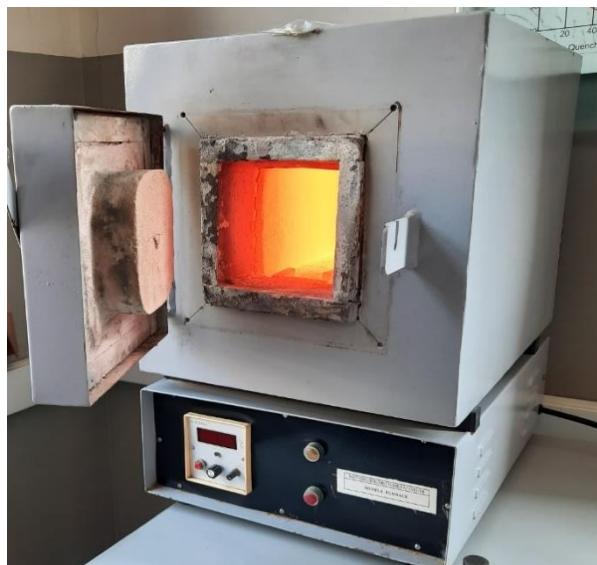


Fig.4 Furnace for polishing of all the heat treated specimen.

All the specimen of SS316 material were polish with the help of polish paper and were given a quite good surface finish by removing all the burrs which were present on the surface of specimen due to heat treatment.

3.9 Testing of impact strength of specimen after heat treatment.

Impact strength of specimen after different heat treatment processes were tested individually with charpy impact tester.

3.10 Testing of hardness of material after heat treatment.

After different heat treatment processes on specimen their hardness was tested again with Rockwell hardness tester.

3.11 Microstructural analysis of specimens after heat treatment.

Microstructure is the very small structure of a material, defined as the structured of a prepared surface of material as revealed by particular microscope above 25× magnification.

3.12 Analysis of effect of heat treatment and notch size on impact strength of material.

After all the testing analysis were done on heat treatment effects on hardness and impact strength and results were obtained and graphs were plotted.

4. Wire Cut EDM (Electrical Discharge Machining)

4.1 Principle

Wire electrical discharge machining (EDM) is a process of metal machining in which a tool discharges thousands of sparks to a metal workpiece. Instead of cutting the material, EDM melts or vaporizes it, leaving little debris and providing a very accurate line.

Wire cut electrical discharge machining (WEDM) is one of the important non-traditional machining processes which are used for machining difficult to machine materials like composites and intermetallic materials. Intricate profiles used in prosthetics and biomedical applications can also be done in WEDM. WEDM involves complex physical and chemical process including heating and cooling. The electrical discharge energy affected by the spark plasma intensity and the discharging time will determine the crater size, which in turn will influence the machining efficiency and surface quality. In WEDM, also known as wire cut EDM and wire cutting.



Fig.5. Machine diagram of Wire cut electro-discharge machining

4.2 Setup

In this machine all the axes are servo controlled and can be programmed to follow a CNC code which is fed through the control panel. All three axes have an accuracy of 1μm. The wire diameter is used as 0.25 mm diameter brass wire. A small gap of 0.025 to 0.05mm is maintained between the wire and workpiece. The high density erodes material from both the wire and workpiece by local melting and vaporizing the dielectric fluid continuously flashed through the gap along wire to sparking area to remove debris produced during erosion. The wires once used cannot be reused again.

The WEDM setup consists of a power supply unit, X-Y table, wire transport system, Dielectric unit and the construction of Upper guide and Lower guide. The power supply unit maintains the constant gap voltage and also control the cutting energy by controlling peak current and spark on-off time. X-Y table Moves along X and Y axes in steps by means of dc servo motors or pulse motors and generates the required profile on the job. In order to produce taper surface, the wire electrode has to be tilted. This is achieved by displacing the upper wire Guide (along U-V axes) with respect to the lower wire guide. The desired taper angle is achieved by simultaneous control of the movement of X-Y table and U-V table. Along their respective predetermined paths stored in the controller. The travelling wire is continuously fed from a wire feed spool and collected on a take up spool which moves through the workpiece and is supported under tension between a pair of wire guides. While the machining is continued, the machining zone is continuously flushed with dielectric fluid passing through the nozzles on both sides of the workpiece. To prevent the ionisation of dielectric fluid, an ion exchange chamber is used in the dielectric distribution system for maintaining the conductivity low.

In this machine, all the axes are servo controlled and can be programmed to follow a CNC code which is fed through the control panel. All three axes have an accuracy of $1\mu\text{m}$. The electrode material used was a 0.25 mm diameter brass wire. A small gap of 0.025 mm to 0.05 mm is maintained in between the wire and work-piece. The high energy density erodes material from both the wire and work piece by local Melting and vaporizing. The di-electric fluid (de-ionized water) is continuously flashed through the gap along the wire, to the sparking area to remove the debris produced during the erosion. A collection tank is located at the bottom to collect the used wire erosions and then is discarded. The wires once used cannot be reused again,

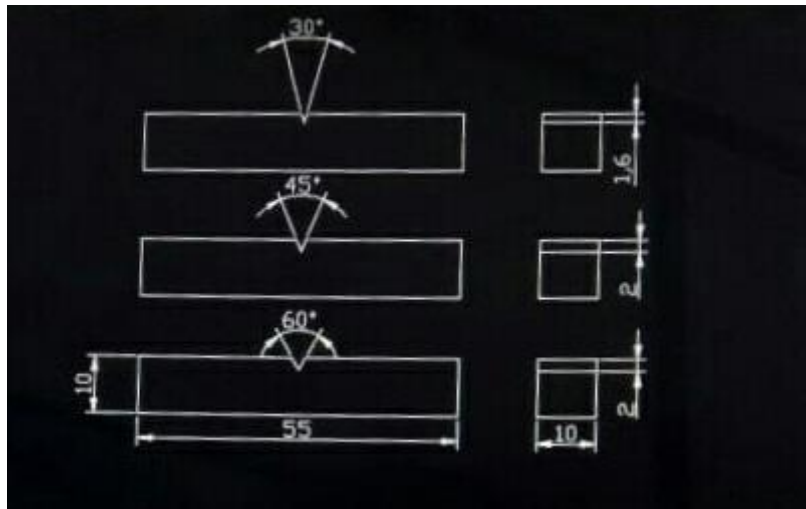


Fig.no.6.notched specimen diagram

In these investigation three different specimens of SS316 material with different notch size were prepared, with notch specifications as follows:

Specimen 1 with notch angle 30° and depth 1.6mm,

Specimen 2 with notch angle 45° and depth 2mm,

Specimen 3 with notch angle 60° and depth 2mm.

After that charpy impact test was done on all the three specimens.

4. Impact strength of the SS316 material before heat treatment

4.1. Impact strength

The impact strength of a material is defined as its capability to resist a sudden applied load or force. It is normally conveyed as the amount of mechanical energy absorbed in the process of deformation under the applied impact loading. Often measured with the Izod impact strength test or Charpy impact test, both of which measure the impact energy required to fracture a sample.

4.1.1. Test on charpy impact tester

The Charpy impact test, also known as the Charpy V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. Absorbed energy is a measure of the material's notch toughness. It

is widely used in industry, since it is easy to prepare and conduct and results can be obtained quickly and cheaply. A disadvantage is that some results are only comparative. The test was pivotal in understanding the fracture problems of ships during World War II. The test was developed around 1900 by S.B. Russell (1898, American) and Georges Charpy (1901, French).The test became known as the Charpy test in the early 1900's due to the technical contributions and standardization efforts by Charpy.

The apparatus consists of a pendulum of known mass and length that is dropped from a known height to impact a notched specimen of material. The energy transferred to the material can be inferred by comparing the difference in the height of the hammer before and after the fracture (energy absorbed by the fracture event).

The notch in the sample affects the results of the impact test,^[6] thus it is necessary for the notch to be of regular dimensions and geometry. The size of the sample can also affect results, since the dimensions determine whether or not the material is in plane strain. This difference can greatly affect the conclusions made.



Fig.7 Charpy Impact Tester

Specimen Dimension: 55mm*10mm*10mm

Position of specimen: Horizontal.

Position of notch: Away from the striker.

Position of striker:Striker hits the center of the test material,behind a machined notch.The notch is positioned away from the striker.

Table no.4 .Result of impact test before heat treatment

Sr.No.	Angle(degree)	Depth(mm)	Impact Strength(J)
Specimen 1	30°	1.6	162
Specimen 2	45°	2	142
Specimen 3	60°	2	133

From the above test we concluded that the specimen having V notch with angle 30° and depth of notch 1.6mm has the highest Impact strength.

5. Hardness of the SS316 material before heat treatment

5.1. Hardness:

Material hardness is the property of the material which enables it to resist plastic deformation, usually by penetration or by indentation. The term of hardness is also referred to stiffness or temper, or to resistance to bending, scratching, abrasion, or cutting. It is the property of a material, which gives it the ability to resist being permanently, deformed when a load is applied. The greater the hardness of the material, the greater the resistance it has to deformation.

5.2. Tests for hardness measurements:

There are several types of hardness tests which are used with accuracy. Since the definitions of metallurgical ultimate strength and hardness are rather similar, it can generally be assumed that a strong metal is also a hard metal. These hardness tests measure the hardness of the metal by determining the resistance of the metal to the penetration of a non-deformable ball or cone. The tests determine the depth which such a ball or cone sinks into the metal, under a given load, within a specific period of time. The most common hardness test methods used these days are (I) Rockwell hardness test (ii) Brinell hardness test (iii) Vickers hardness test.

5.3 Rockwell hardness test

Rockwell hardness test is a hardness measurement method which is based on the net increase in depth of impression as a load is applied. Rockwell hardness test is the most used and versatile of the hardness tests. In the Rockwell method of hardness testing, the depth of penetration of an indenter under certain arbitrary test conditions is determined. The indenter is spherical diamond tipped cone called which is of 120 degree angle and 0.2 mm tip radius.

A minor load of 10 kg is first applied, which causes an initial penetration and holds the indenter in place. Then, the dial is set to zero and the major load is applied. Upon removal of the major load, the depth reading is taken while the minor load is still on. The hardness number may then be read directly that is 27HRC



Fig.8 Rockwell Hardness Tester

**Fig.9 Indenter****Result:**

The hardness of the material was found to be 27HRC

6. Microstructure of SS316 material

When describing the structure of a material, we make a clear distinction between its crystal structure and its microstructure. The term 'crystal structure' is used to describe the average positions of atoms within the unit cell, and is completely specified by the lattice type and the fractional coordinates of the atoms.

The microstructure of a material can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, high or low temperature behaviour or wear resistance. These properties in turn govern the application of these materials in industrial practice. Microstructure at scales smaller than can be viewed with optical microscopes is often called nanostructure, while individual atoms are arranged is known as crystal structure.

7. HEAT TREATMENT

Heat treatment performed on the SS316 material are

1. Annealing
2. Quenching
3. Normalizing

7.1. Annealing

Annealing is a heat treatment that alters the physical and sometimes chemical properties of a material to increase its ductility and reduce its hardness, making it more workable. It involves heating a material above its recrystallization temperature, maintaining a suitable temperature for a suitable amount of time, and then allowing slow cooling.

In annealing, atoms migrate in the crystal lattice and the number of dislocations decreases, leading to a change in ductility and hardness. As the material cools it recrystallizes. For many alloys, including carbon steel, the crystal grain size and phase composition, which ultimately determine the material properties, are dependent on the heating rate and cooling rate. Hot working or cold working after the annealing process alter the metal structure, so further heat treatments may be used to achieve the properties required. With knowledge of the composition and phase diagram, heat treatment can be used to adjust from harder and more brittle to softer and more ductile.



Fig.10 Cooling of specimen in the furnace

7.2. Quenching

Quenching is the rapid cooling of a workpiece in water, oil or air to obtain certain material properties. A type of heat treating, quenching prevents undesired low-temperature processes, such as phase transformations, from occurring. It does this by reducing the window of time during which these undesired reactions are both thermodynamically favourable, and kinetically accessible; for instance, quenching can reduce the crystal grain size of both metallic and plastic materials, increasing their hardness.

In metallurgy, quenching is most commonly used to harden steel by introducing marten site, in which case the steel must be rapidly cooled through its eutectoid point, the temperature at which austenite becomes unstable. In steel alloyed with metals such as nickel and manganese, the eutectoid temperature becomes much lower, but the kinetic barriers to phase transformation remain the same. This allows quenching to start at a lower temperature, making the process much easier. High speed steel also has added tungsten, which serves to raise kinetic barriers, which among other effects gives material properties (hardness and abrasion resistance) as though the workpiece had been cooled more rapidly than it really has. Even cooling such alloys slowly in air has most of the desired effects of quenching; high-speed steel weakens much less from heat cycling due to high-speed cutting.^[1]

Extremely rapid cooling can prevent the formation of all crystal structure, resulting in amorphous metal or "metallic glass".



Fig.11 sudden cooling of specimen in water (Quenching)

7.3. Normalizing

Normalizing is a heat treatment process that is used to make a metal more ductile and tough after it has been subjected to thermal or mechanical hardening processes. Normalizing involves heating a material to an elevated temperature and then

allowing it to cool back to room temperature by exposing it to room temperature air after it is heated. This heating and slow cooling alters the microstructure of the metal which in turn reduces its hardness and increases its ductility.



Fig.12. Air cooling of specimen

8. EFFECT OF HEAT TREATMENT ON IMPACT STRENGTH AND HARDNESS:

8.1. Effect of Annealing on Impact strength of SS316 material

After the Annealing of specimen of SS316 material impact strength was measured again and it was found that impact strength of specimen with V notch of 30° and depth of 1.6mm was maximum and it was increased to 297 joule from 162 joule.

Table no.5Result table of Annealing on Impact strength of SS316 material

Sr no.	Notch angle(in degree)	Depth of notch(in mm)	Impact strength before (in joule)	Impact Strength after(in joule)
Specimen 1	30	1.6	162	297
Specimen 2	45	2	142	294.5
Specimen 3	60	2	133	295

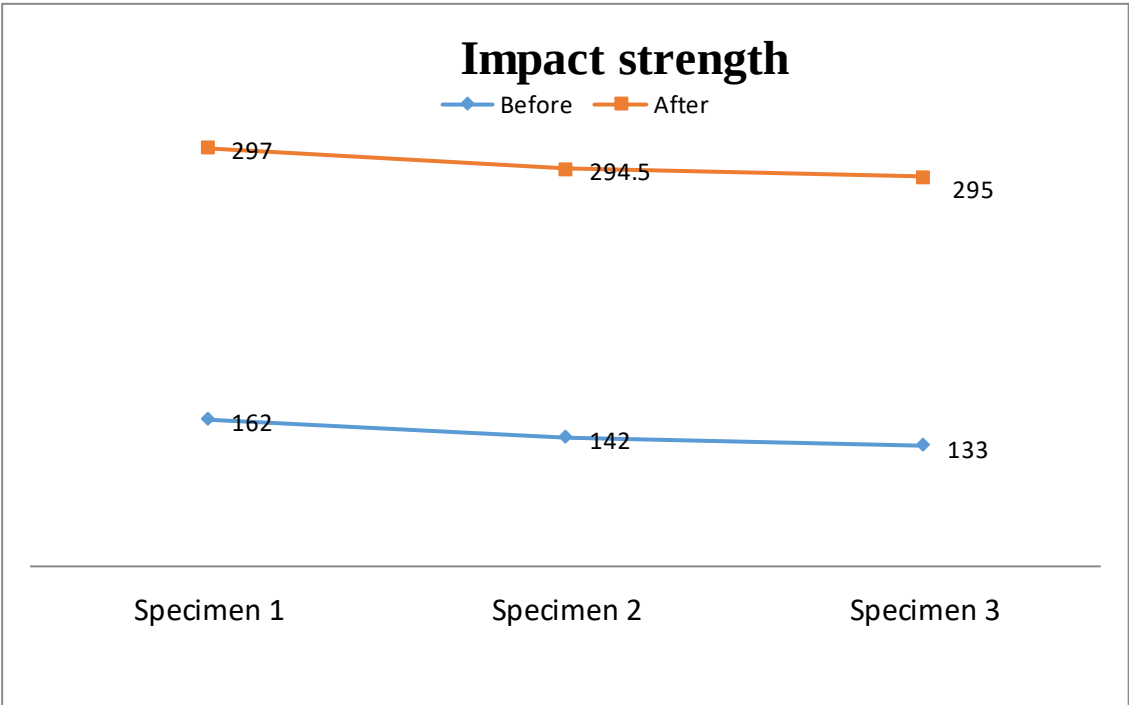


Fig.no.14 .Effect of Annealing on Impact strength of SS316 material

8.1.2. Effect of Annealing on hardness of SS316 material

After the annealing of specimen of SS316 material hardness was measured again and it was found that hardness of specimen increases from 27 HRC to 83 HRC.

8.1.3. Change in Microstructure after Annealing

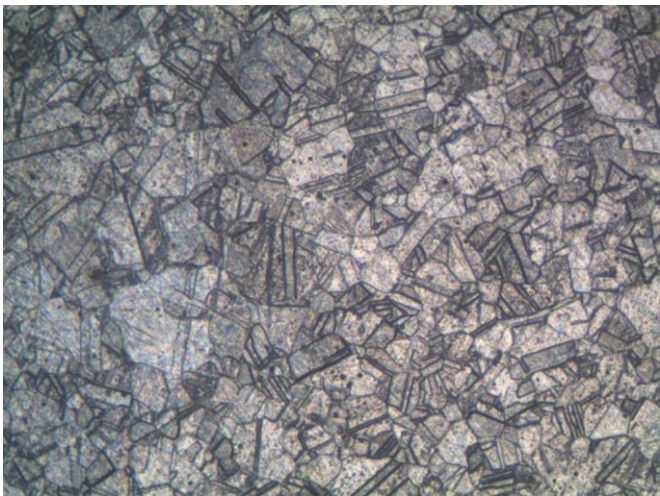
Test Method:-Asm-Handbook-V-9, Is 4748:2009.

Etching Agent:-Glyceresia

Magnification:-100 X, 200x, 500x

Microstructure:-The Structure Shows Grains of Austenite.

Grain Size (100 X):- The Grain Size No. 4 To 6 (By Comparison Method) As Per Is 4748:2009.



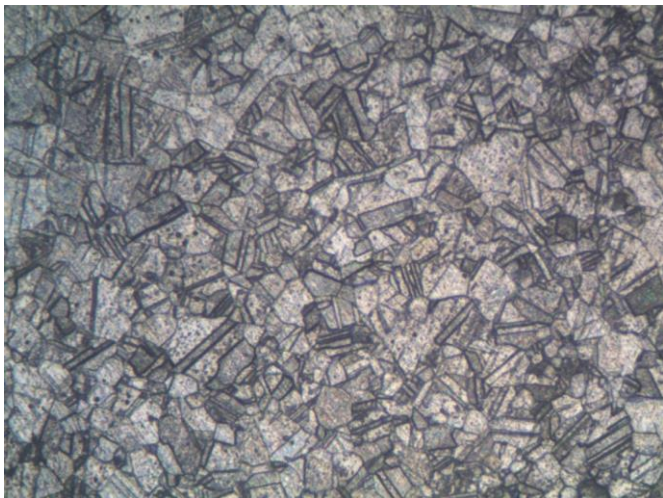


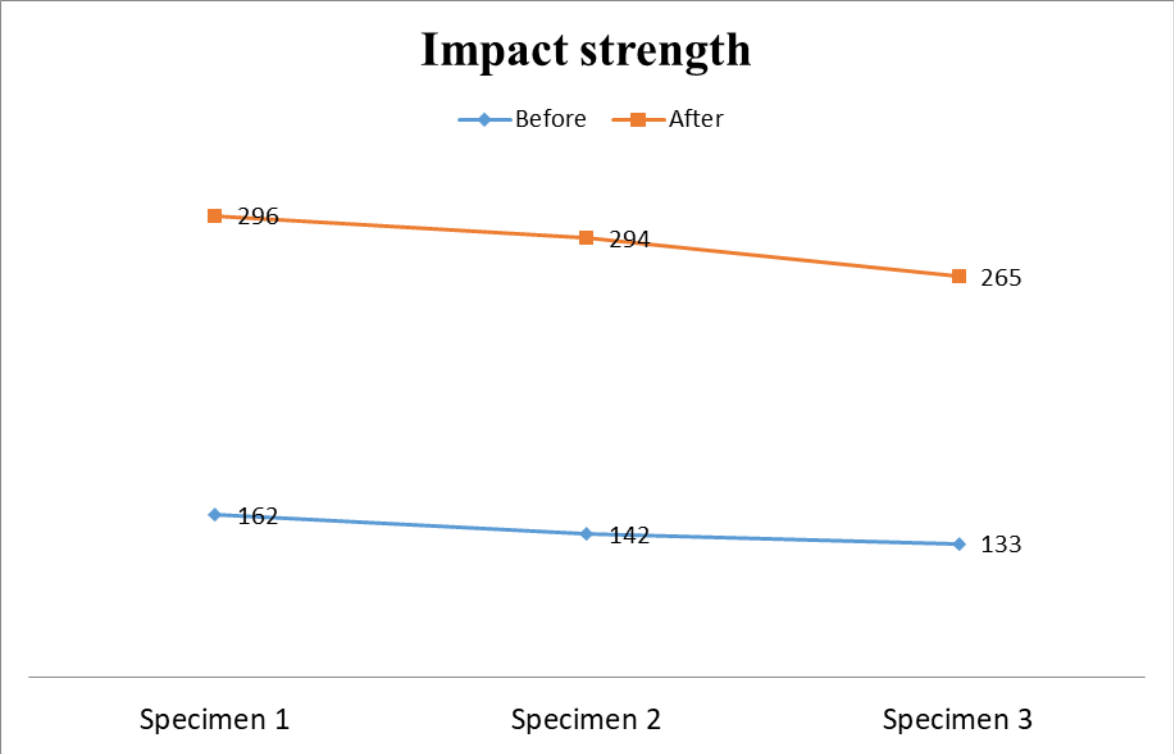
Fig.no.14.Change in Microstructure after Annealing

8.2. Effect of Quenching on Impact strength of SS316 material

After the quenching of specimen of SS316 material impact strength was measured again and it was found that impact strength of specimen with V notch of 30° and depth of 1.6mm was maximum and it was increased to 296 joule from 162 joule.

Table no.6 Result of Effect of Quenching on Impact strength of SS316 material

Sr no.	Notch angle(in degree)	Depth of notch(in mm)	Impact strength before (in joule)	Impact Strength after(in joule)
Specimen 1	30	1.6	162	296
Specimen 2	45	2	142	294
Specimen 3	60	2	133	265



8.2.2. Effect of Quenching on Hardness of SS316 material

After the quenching of specimen of SS316 material hardness was measured again and it was found that hardness of specimen increases from 27 HRC to 79 HRC.

8.2.3. Change in Microstructure after Quenching.

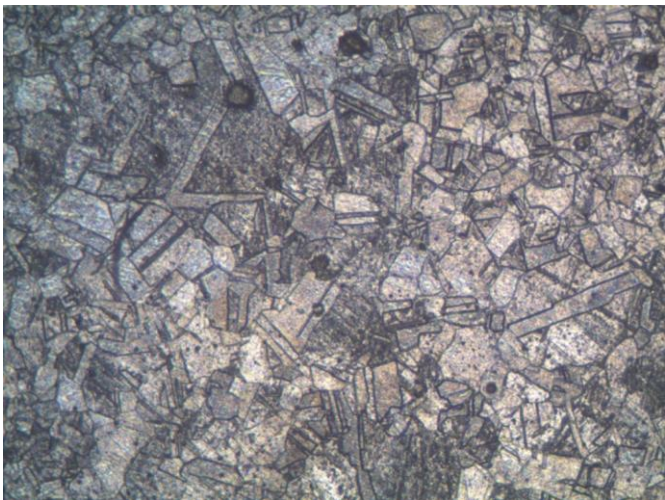
Test Method:-Asm-Handbook-V-9, Is 4748:2009.

Etching Agent :-Glyceregia

Magnification:-100 X, 200x, 500x

Microstructure:-The Structure Shows Grains of Austenite.

Grain Size (100 X):- The Grain Size No. 4 To 6 (By Comparison Method) As Per Is 4748:2009.



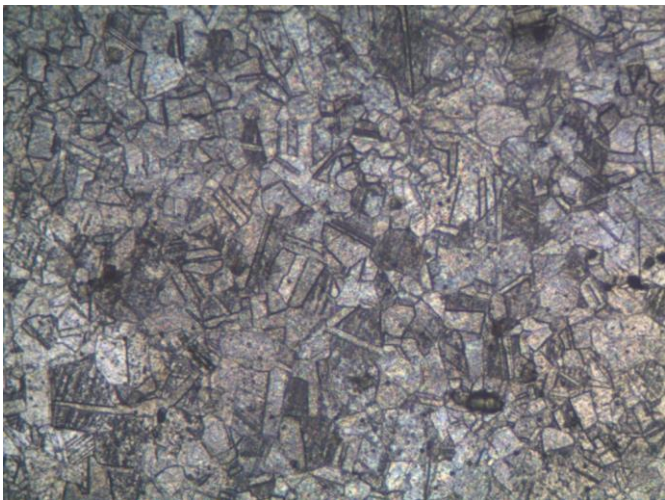


Fig.no.15 Effect of Quenching on Hardness of SS316 material

8.3. Effect of Normalizing on Impact strength of SS316 material

After the Normalizing of specimen of SS316 material impact strength was measured again and it was found that impact strength of specimen with V notch of 45° and depth of 2mm was maximum and it was increased to 294 joule from 142 joule.

Table no 8 result of Effect of Normalizing on Impact strength of SS316 material

Sr no.	Notch angle(in degree)	Depth of notch(in mm)	Impact strength before (in joule)	Impact Strength after(in joule)
Specimen 1	30	1.6	162	292
Specimen 2	45	2	142	294
Specimen 3	60	2	133	291

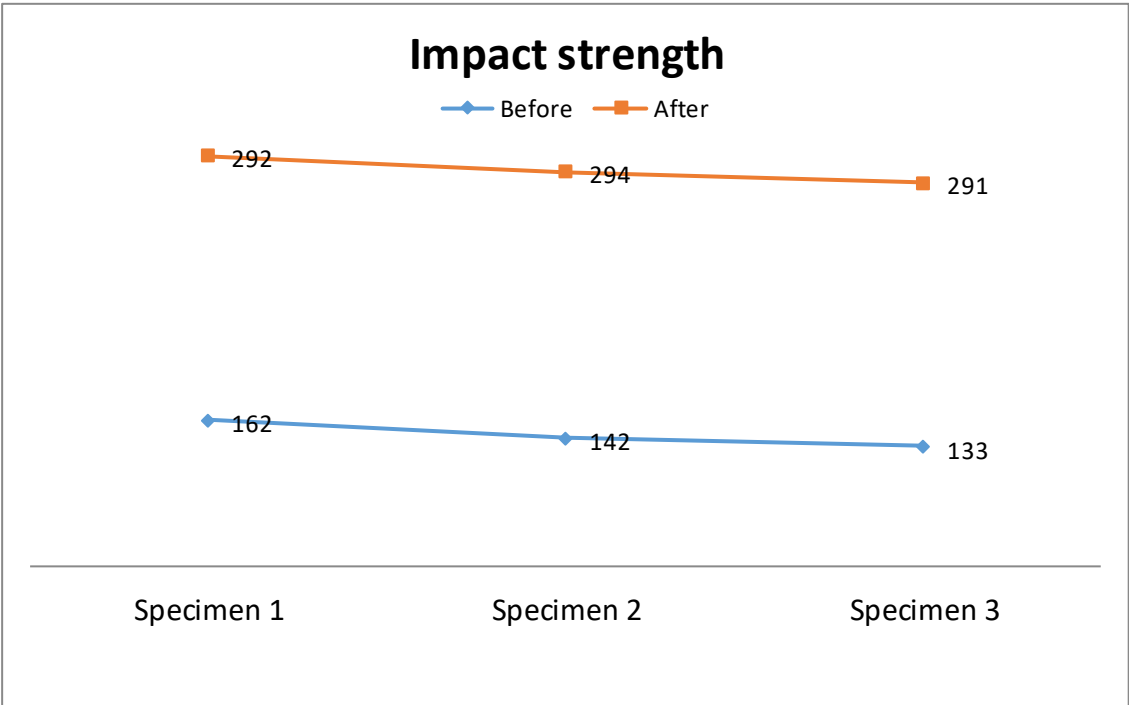


Fig.no.16 Effect of Normalizing on Impact strength of SS316 material

8.3.2. Effect of Normalizing on Hardness of SS316 material

After the Normalizing of specimen of SS316 material hardness was measured again and it was found that hardness of specimen increases from 27 HRC to 30 HRC.

8.3.3. Change in Microstructure after Normalizing.

Test Method:-Asm-Handbook-V-9, Is 4748:2009.

Etching Agent:-Glyceregia

Magnification:-100 X, 200x, 500x

Microstructure:-The Structure Shows Grains of Austenite.

Grain Size (100 X):- The Grain Size No. 4 To 6 (By Comparison Method) As Per Is 4748:2009.

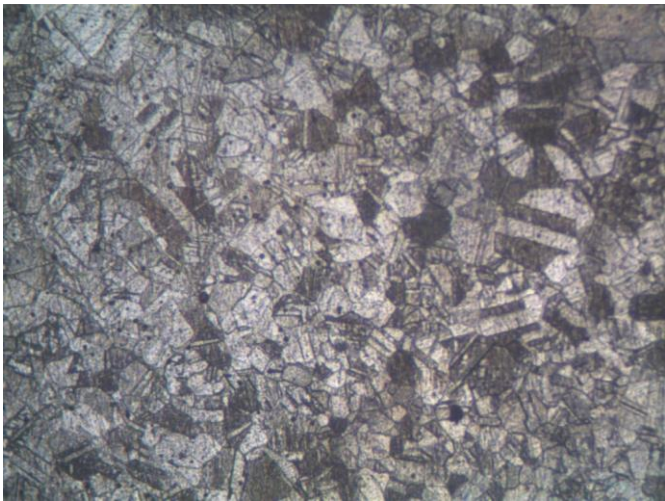


Fig.no.17 Change in Microstructure after Normalizing.

9. CORRELATION BETWEEN IMPACT STRENGTH AND HARDNESS

9.1. Effect of Heat treatment on Impact strengthof SS316 material

Table no.9.Result of Effect of Heat treatment on Impact strengthof SS316 material

Sr no.	Notch angle(in degree)	Before	Annealing	Quenching	Normalizing
Specimen 1	30	162	297	296	292
Specimen 2	45	142	294.5	294	294
Specimen 3	60	133	295	265	291

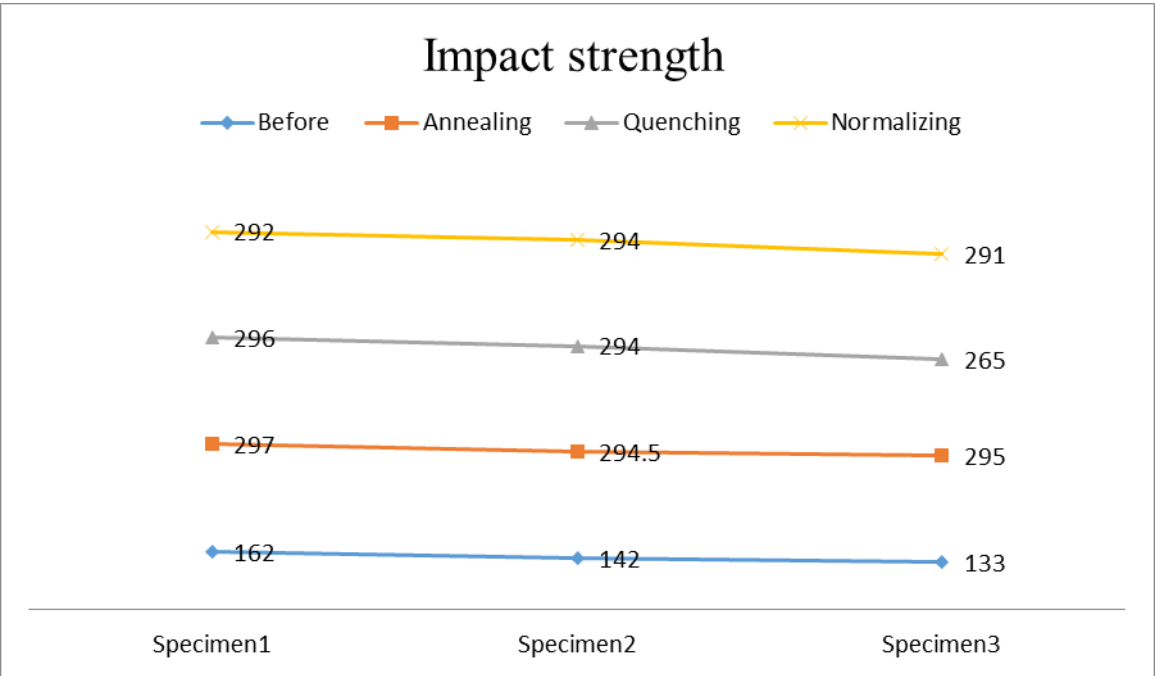


Fig.no.17.Effect of Heat treatment on Impact strengthof SS316 material

9.2. Effect of Heat treatment on hardness of SS316 material

Table no.10 Result of Effect of Heat treatment on hardness of SS316 material

Sr no.	Notch angle(in degree)	Depthof notch(in mm)	Hardness before (in HRC)	Hardnessafter(in HRC)
Specimen 1	30	1.6	27	83
Specimen 2	45	2	27	79
Specimen 3	60	2	27	30

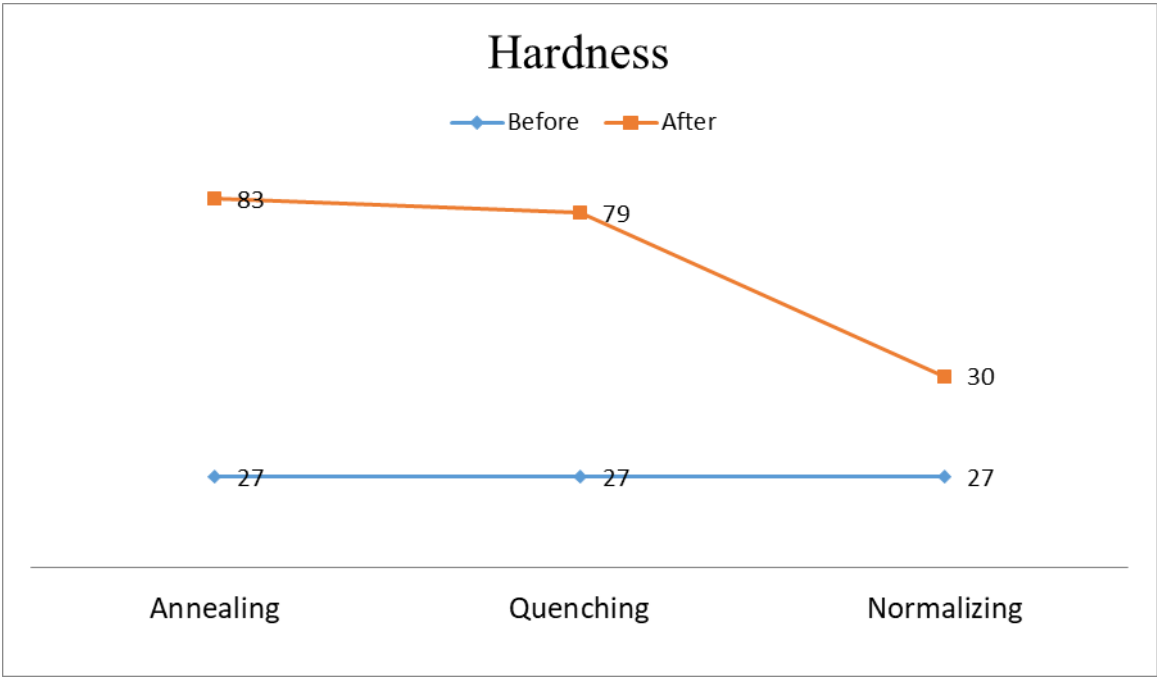


Fig.no.18 Effect of Heat treatment on hardness of SS316 material

10. Applications of Stainless steel 316

Initially developed for use in paper mills Stainless steel 316 is now typically used in:

- Food processing equipment
- Pressure vessels
- Brewery, dairy, and pharmaceutical production equipment
- Chemical and petrochemical equipment
- Laboratory benches & equipment
- Coastal architectural panelling
- Boat fittings
- Chemical transportation containers
- Heat exchangers
- Mining screens
- Nuts and bolts
- Springs, nuts, bolts and screws
- Medical implants
- Sinks and splashbacks
- Saucepans
- Cutlery and flatware
- Sanitary ware and troughs
- Tubing

12 .References

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