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Effect of Heat Treatment Processes on Metals and Alloys-A Review

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ABSTRACT: Heat treatment can be simply defined as heating, holding and cooling of materials. The current review paper presents the various types of heat treatment processes done on the different metals and alloys. A comparative analysis of the effect of heat treatment on hard-ness, yield strength and microstructure etc. of the various metals and alloys has been pre-sented in this paper. The literature has shown that the heat treatment resulted in the devel-opment of new phases along with the improvement of microstructural and mechanical properties of various metals and alloys. The paper also represents the consequence of mi-crowave heat treatment done on various substrates. The final part of the paper discusses the suggested future work that can be done.

Keywords: Heat Treatment, Heat Treatment of Metals and Alloys, Microstructure characteriza-tion, Mechanical characterization, Microwave Heating.

1 INTRODUCTION

Heat treatment plays an important role on the characteristic properties of metals and alloys. Basically, it is the selection of type of heat treatment that can improve or change the properties of material. There are various types to heat treatment which can be utilized for the improved performance of the metal & alloys viz. annealing, normalizing, tempering, hardening, case hardening, vacuum and microwave heat treatment etc. [1]. Every type of heat treatment process has a different impact on the performance of the metal and alloys. Literature has shown that the high fraction retained austenite can be achieved from (Q&P) quenching and portioning processes [2]. Generally, the strength and hardness of the metal and alloys must be high to be utilized for various engineering applications. Now a days the main focus of researchers is to finding some novel type of heat treatments e.g. Microwave heat treatment, vacuum heat treatment (vacuum carburizing, vacuum nitriding, vacuum carbo-nitriding, vacuum brazing, and vacuum sintering), that can be used to improve or change the material properties.

Vacuum heat treatment is a new type of heat treatment process, which increases the heat-treating quality; reduces cost and eco-friendly also. A time saving of about 33-50% can also be achieved through this process as compared to the atmospheric process [3]. Microwave heat treatment is also such a novel technique which heats a material uniformly and more evenly at molecular level. In microwave heat treatment the material is heated from inner core to outer surface but in conventional heat treatment metal is heated from surface to inner core which takes long time for homogenization and resulted in the development of internal stresses also. Microwave heat treated metals have high hardness and fracture strength as compare to conventional heat treatment and it uses very less energy and time as compared to conventional heat treatment. Surface treatments like; carburizing, boronizing, carbonitriding etc. can also be performed by microwave heat treatment [4].

Heat treatment is mainly divided into 3 processes and these processes are: annealing, quenching and tempering. It is also observed in the literature that electricity and heat conducting ability can also be affected by the application of heat treatment process [5].

1.1 Heat Treatment Processes

a) **Annealing**
Material is heated near to its critical temperature, hold/soaked at that temperature for 1 to 2 hours and then slowly cooled in furnace to the room temperature. The basic purpose of this process is to relieve internal stresses; refine grain structure, increase ductility and machining ability [6].

b) **Normalizing**
In this process material is heated up to 40-50° C above the critical temperature and hold/soaked for some time and then followed by slowly cooling in the air. Normalizing is generally used only for ferrous metals. This process is used to remove internal stresses of ferrous metals [7].

c) **Hardening**
It is a heat treatment process used to increase hardness, strength of material and make it less ductile. In this process material is heated at a certain temperature, hold and then cool suddenly in water, oil or brine solution. Quenching is a rapid cooling process, which is used for hardening. As hardness of material increases it becomes more brittle. So, its brittleness can be removed by tempering process [7].

d) **Tempering**
After hardening of material, tempering is carried out to release the internal stresses which are developed during the hardening process. The tempering process includes the re-heating of material to 780° C-820° C, followed by holding it for some time and then slowly cooling in the air. Tempering of material is done to reduce the hardness, restoring of ductility, toughness and shock resistant property [7].

e) **Microwave heat treatment**
Microwave can also be used to heat materials especially metals and alloys, but some special set of arrangement is required to heat treat a metal part. As a heat insulator, layer of aluminum oxide is used to mask the metal and then as a subsector a layer of graphite is used to cover that metal part. After this set metal part is heat treated at some temperature and this temperature is controlled by temperature controller [2].

The next part of this paper discusses the outcome of various heat treatment processes performed on the different metal and alloys.

II LITERATURE REVIEW

K. Khera et al. [1] have studied the mechanical properties and microstructure of EN31 & EN8 carbon steel, affected by the heat treatment. A comparative analysis of hardness, microstructure and corrosion rate of EN-31and EN-8 carbon steel before and after the heat treatment was done by the author. Heat treatment processes like: - annealing, oil-quenching and tempering was done on carbon steels. Hardening was done at the temperature of 820° C-860° C on EN31 and on EN8 hardening was done at a temperature of 750° C-900° C. Result demonstrated that high hardness value was achieved by oil quenching and highest elongations was achieved by annealing process.

The effect of heat treatment on the advanced high-strength steels was analysed by D. Bublikova et al. [2]. Four experimental steels were taken in which Mn, Si, Cr, Mo & Ni are the main elements and that steel was further treated by Q&P process with consequently interrupted by quenching which resulted in martensite and retained austenite mixture structure. More than 2000MPa strength level with the elongation of 10%-15% was achieved after the heat treatment. Steel with these properties can be used for the manufacturing of light weight complex closed-die forgings. D. Sonawane et al. [3] presented a review on heat treatment optimization and the latest trends in the field of heat treatment. The paper exhibited that the market is concentrated more on optimization of cost, efficient usage of energy and eco-friendly heat treatment processes because of their high demand. Heat treatment and surface engineering are helping to increase the use of materials in the industries of automobile, aerospace and weapons. Many novel techniques of heat treatment have been utilized by the researchers viz. vacuum heat treatment, quenching media development, laser heat treatment, electromagnetic process, and intensive quenching due to which the case depth has been increased to 30 %, process time is decreased by 25-30% and the consumption of energy decreased up to 30%.

The effect of microwave heat treatment on the properties of AA6061 was studied by D. Loganathan et al. [4]. Main objective of this research was to exclude the pitfall by microwave heat treatment process which gave uniform distribution of temperature and increases mechanical and physical properties of metal with the reduced consumption of power. The outcome results showed an improvement in the hardness, yield strength and tensile strength with a saving of time. N. M. Ismail et al. [5] studied the impact of heat treatment on the hardness and properties of medium carbon steel. Annealing, quenching and tempering processes were performed on carbon steel during all the investigations. During the annealing process the sample was heated at 900° C, holded for 1 hour in furnace and then quenched in water and open air medium. After that, the specimen was succeeded at 300° C, 450° C & 600° C with 2 hour holding time for tempering process. After the completion of heat treatment process, hardness and impact strength were tested on Rockwell hardness & charpy impact test and obtained result were analysed and compared. SEM was used to test the fractured surface. The results revealed that the highest hardness value was obtained in water quenched specimen. A good combination of decreased brittleness, increased toughness and ductility were obtained from the microstructure of specimen after the tempering process.

The impact of heat treatment on the mechanical properties of H11 tool steel was studied by S.Z.Qamar [6]. Heat treatment processes like annealing, hardening, oil or air quenching were done on the samples and after all these processes tensile strength, hardening, impact toughness were tested. Result showed that the hardness value of sample initially increased and then decreased gradually. The value of impact toughness decreased to lower value and then finally increased whereas the strength value increased to higher value and then decreased slowly. The value of ductility decreased at 600° C and after then increased rapidly. S. D. Parikh et al. [7] analysed the effect of heat treatment on EN31 tool steel. The main aim of this work was to increase the hardness value & machinability with the reduced internal stress of EN31 by the application of heat treatment. The results exhibited that, by the increased % of carbon, hardness of EN31 was also increased. Machinability of EN31 tool steel was increased and internal stresses were removed with the application of heat treatment.

The effect of heat treatment process on the microstructure and mechanical properties of Al-12 Si produced by SLM (selective laser manufacturing) was studied by K.G. Prashanth et al. [8]. Annealing was done on Al-12Si material and it was observed that along the cellular boundaries, a residual free Si with fine cellular structure was present. The yield and tensile strength of sample was improved to 260MPa & 380MPa respectively. An improvement of approximate 3% in the fracture strain was also recorded by the author. T. Engdahl et al. [9] investigated fine scale precipitates in Al-Zn-Mg alloy after the heat treatment at a temperature of 150 ° C. Two materials with different ratios of Zn: Mg which was free from copper and one material with little ratio of Zn had been studied in this paper. Hardening treatment and ageing treatment were done on the specimens. For all used heat treatment, the GP2 (Guinier-preston zone) zone presence showed in electron diffraction pattern of copper free material of selected area and GP1 zone was observed in a material which had less copper. The ratio of Zn: Mg was decreased and density of particle number got lesser as time of heat treatment increased. The changes in mechanical properties of multi-element wear-resistant low-alloy steel after application of heat treatment was analysed by J. Z. et al. [10]. Hardening and tempering were done on MLAWS. Rolling mill torus liner was made by MLAWS material. When the temperature of quenching was less than 900° C, then the value of hardness was increased & impact toughness was decreased with the increase of temperature & vice-versa. Hardness of specimen was decreased when tempering temperature was greater than 450° C. Best wear resistance was achieved at the temperature of 450° C during tempering. The MLAWS was tempered at 350° C-370° C and quenched at 900° C -920° C according to the service condition of rolling mill torus.

P. Biswas et al. [11] studied the microstructural behavior and hardness of EN8 steel after the implementation of heat treatment process. EN8 steel was annealed at 820° C for 45 minutes, normalized at 850° C for 2 hours, quenched in oil and tempered at 300° C in this research work. Tempering of EN8 was done after every heat treatment to analyse its effects. The results exhibited that the hardness value of EN8 steel was adequate when tempering was done after normalizing and a fine grain microstructure was observed during the microstructural investigations. Ahaneku I.E. et al. [12] have used different quenchants like: - water, air, oil & brine to improve the mechanical property of mild steel after the application of heat treatment. 6 samples were heat treated at a temperature of 900° C for 4 hours and then quenched. Quenching media for each sample was different and then various mechanical properties were tested at UTM. It was observed that the water quenchant was better medium for mild steel which gave greatest value of tensile strength 497.76 N/mm^2, yield strength 749.49N/mm^2, toughness 168.38 and 138.27 BHN hardness. A lesser value of ductility about 28.36% with the water as quenchant in comparison to other quenchants was also recorded by the author.

Spheroidization heat treatment of medium carbon alloy steel was studied by Harisha S. R. et al. [13]. Sub-critical and inter-critical annealing was done on AISI 4037 steel and the respective comparison was also done by the author. Inter-critical annealing was done at 748° C for 2 hour and sub-critical annealing was done at 704° C for 10 hours. Spheroidizing heat treatment was used to increase the formability and machinability of medium carbon low alloy steel as well as high carbon low alloy steel. The tribological and impact resistance, stiffness, abrasive resistance and strength were also improved. Y. P. Lim et al. [14] have studied about the heat treatment of gravity die-cast Sc-A356 Al alloy and their effects on microstructure and mechanical properties. The preparation of sample was done according to ASTM B557-06 standard by gravity die-casting. Sample was heat treated by Spheroidizing at temperature of 540° C for 8 hours succeeded by water quenching and artificial aging at temperature of 160° C for 6 hours. SEM, OM, Vickers hardness tester and instron static machine was used to check the microstructure, micro hardness and tensile strength of developed samples. The grain size of samples effectively decreased from 40 µm to 16 µm after heat treatment and tensile strength and micro hardness were increased to 338 MPa and 118HV respectively.

Effect of heat treatment on impact toughness and grain size of medium carbon steel at low temperature was studied by Samuel J. Rosenberg et al. [15]. Normalizing, hardening, tempering was done on medium carbon steel. There was no relation showed between grain size and impact toughness. Result demonstrated that the impact toughness of steel was found low in normalized treated specimen but high in hardened and tempered treated specimen. A. D. Isadare et al. [16] have studied the mechanical properties of 7075 Al alloy effected by heat treatment process. In this paper annealing and age hardening heat treatment was done on sample of round shaped cylindrical rod made from 7075 Al alloy. Mechanical testing and morphology of microstructure was examined by OM (optical microscopy). From the results, at time of gradual solidification, microsegration formation of $MgZn_2$ was obtained and at the time of rapid cooling microsegration was not presented. Mechanical property of 7075 Al alloy was improved by age hardening and annealing heat treatment.

An investigation of the wear resistance of AISI H13 tool steel after the application of conventional heat treatment was studied by Bahrami et al. [17]. AISI H13 tool steel was oil quenched, hardened at 1050° C and tempered at 600° C. Wear behavior was studied on pin on disc arrangement at the load values of 29.4 & 98 N and a speed of 0.07m/s. SEM and X-Ray method was used to study wear tracks and debris. The results showed that, at 600° C when load was less than 29.4N for 30-60 minutes then the quenched specimen had highest wear resistance and mixture of oxides & plate like metallic powder. Tempered specimen had maximum wear resistance at the load value of 98N. A. Kesner et al. [18] have studied about the isothermal heat treatment of steel in salt bath and its effect on microstructural changes of the steel. Sample was heat treated by hardening at 1200° C and 1020° C and tempered at 550° C and 500° C. Air and oil were used as the quenching media. Result demonstrated that the maximum value of hardness was found when specimen was isothermal tempered in salt bath with low process time and lowest hardness value obtained when specimen was isothermally heat treated in hot salt bath.

B. Skela et al. [19] have investigated the microstructural changes of heat treated hot worked tool steel S361R & its effects on mechanical and wear properties. In this paper, sample were heat treated for 15 minutes at temperature of 1030° C in horizontal vacuum furnace and quenched with nitrogen gas and after completion of all these process, hardness, impact toughness, tensile strength and wear were tested. A sample was quenched for 2 times at decided temperature for 2 hours each time. Temperature of 1st quenched time was 500° C and temperature of second quenched time was 640° Celsius with 30° C increment for every set of sample. Result showed that the martensitic matrix microstructure of heat treated sample had different carbide distribution. As counter body of 100Cr_6 & Al_2O_3 balls were used to obtain adhesive and abrasive wear mechanisms. By use of 100 Cr_6, combination of adhesive and abrasive was found for every sample which had different value of hardness. The results revealed that hardness was decreased with increased wear and when Al_2O_3 was used as counter ball then the coefficient of friction was also increased.

X.M. Zhang et al. [20] studied the wear and friction properties of EN31 after the surface was hardened by CO_2 laser. A comparative analysis was done on treated surface by use of lubricated ring on block. SEM was used to observe the laser hardened tracks and worn surface microstructure. In comparison of untreated surface, a good wear friction property was found in single hardened track surface. In addition to that a good friction property were observed in non-overlapping track surface in comparison of single track homogeneous hardened zone. M. N. Sari et al. [21] have studied the impact of heat treatment on microstructure of H23 tool steel. An austenization temperature of 1106° C & 1250° C were maintained for the investigations. In addition to this a temperature of 650° C, 750° C and 800° C were maintained for water quenching. 1st double aged & 2nd aged treatment were cooled with air. Ferrite matrix, M6C, M7C3, and MC carbides were present in microstructure of as-quenched sample. Result showed that after austenization, hardness of H23 tool steel was improved to 448 HV at 1250° C.

The change in hardness value of heat treated EN8 tool steel was studied by B. Singh et al. [22]. Annealing, normalizing, hardening and tempering process were performed on sample. Mechanical and chemical analysis was done on the developed samples. Hardness test was also done on both treated and untreated sample. Result demonstrated that the EN8 tool steel become more ductile after annealed treatment, hardness was increased after the normalizing of sample in comparison of untreated sample. Specimen became hardest after hardened and tempered treatment because of the formation of martensite. G. Y. Back et al. [23] have studied about the properties of heat treated high wear resistant (HWS) tool steel. DED (direct energy deposit) was used for the deposition of high-wear resistant steel to repair and hard the face. Heat treatment of HWS deposits had higher hardness and wear resistance value in comparison of untreated HWS deposited samples.

T. Sonar et al. [24] attempted to minimize the heat treated AISI D2 tool steel distortions. Fast cooling of steel was achieved by quenching process which gave the transformation of phase from austenite to martensite. Mechanical component distortion and surface integrity were also affected by this process. Minimum deviation in dimension was showed by deep cryogenic treatment. As compare to conventional heat treatment, the surface finish and hardness were increased by 13.43% and 1.26% with deep cryogenic heat treatment. S. Pandarkar et al. [25] studied the mechanical property of EN31 die block after application of heat treatment. Annealing, normalizing, tempering and hardening were done on samples of EN31 steel at different temperatures of 800° C, 900° C and 1000° C respectively. Specimens were quenched with different media viz. oil, air and water. Various stresses were produced at the time of machining which were reduced by heat treatment. The heat treatment of EN31 steel at

800° C with water quenching resulted in improved hardness of 63 HRC hardness, tensile strength of 851N/mm^2, yield strength of 567.33N/mm^2 with a maximum toughness of 18 joule respectively.

J.A. Menendez et al. [26] have investigated the properties of carbon materials after exposed to microwave heat treatment. The carbon material which are produced, transformed and thermally heat treated by microwave-assisted process were reviewed and the achieved results were compared with the result of conventional treated in same conditions. The result revealed that the carbon material was good in microwaves absorption. Time scale and energy consumption were decreased. H.W.Lee et al. [27] investigated the gas nitriding effects on 17Cr-1Ni-0.5C (CN) steel at high temperature and tempering temperature. At 1050° C HTGN was performed for 1 hour with 98.07 KPa of nitrogen in gaseous atmosphere. After HTGN, approx. 0.3% of nitrogen was found below the layer of surface at depth of 5 μm in CN specimen. Hardness achieved by outmost surface of specimen was 538HV and 860HV. Surface hardness was achieved when the sample was tempered for 1 hour at 550° C which was resulted due to the precipitation of Cr_2N with $Cr_{23}C_6$ & secondary hardening effect.

B. Singh et al. [28] analysed the effect of plasma nitriding heat treatment on EN31 steel and their effects on abrasive wear. In this research work a comparative analysis was done on micro hardness, microstructure and abrasive resistance of EN31steel and plasma nitriding heat treated EN31. EN31was heat treated at ta emperature of 510° C by plasma nitriding for 1 hour in the environment of nitrogen and hydrogen. RWAT (rubber wheel abrasion tester) was used to test the abrasive wear and OM (optical microscope) and SEM (scanning electron microscope) was used to test the microstructure property and surface property. Average micro hardness was found more in nitriding (183.3HV) and better wear behavior achieved by nitride steel. The result showed a good wear behavior by plasma nitride samples. Weight loss increased slowly with the increase of flow rate of abrasive particle from 100 gm/min. to 200 gm/min.

M. Ramezani et al. [29] have studied the heat treated H13 tool steel under the different atmospheric conditions. In this paper "vacuum heat treatment, pack carburizing heat treatment, heat treatment with foil wrapped stainless steel and without atmospheric control heat treatment were studied and result showed decarburization process restricted by foil wrapping stainless steel. A constant hardness by the specimens was achieved by the vacuum heat treatment. N.EI-Bagoury et al. [30] have studied the microstructure and mechanical properties of Ni based super alloy which was heat treated at several conditions of different temperatures of 1120° C and 1180° C. Ni based super alloy was solution treated for 2 hour and cooled by air before its aging process was done for 24 hour at 845° C temperature. Coarse grain size was observed in heat treated aged sample at 1180° C. Higher primary particle V_F value was observed in 1120° C treated aged alloy than 1180° C treated aged alloy. ICP-AES (inducticuly coupled plasma atomic emission spectroscopy) was used to test the corrosion wear. The results exhibited that at 1120° C temperature, rate of corrosion of aged treated alloys was higher than the 1180° C temperature aged treated alloys.

A.Joseph et al. [31] investigated that the wear resistance of EN 31 steel could be improved by deep cryogenic treatment. Sample was heat treated by deep cryogenic at different conditions to enhance the mechanical properties of EN31. SEM was used to check the wear rate of cryogenic treated EN31 steel sample. The result exhibited that 75% wear could be decreased by deep cryogenic treatment and it was depended upon the EN31 service conditions. From results it was noticed that, to achieve more improved performance the tempering of specimen was done after cryogenic treatment. R. Flip [32] has studied the outcomes of laser nitriding heat treatement on Ti6A14V titanium alloy. Laser nitride heat treatment was done on titanium alloy. Surface hardness was tested under 196N load by Vickers hardness. Pin & Disc test T08M machine were used to for wear characterization. The results showed that the hard ceramic particles of TiN & Ti_2N were found on surface layer of treated sample. Due to this TiN & Ti_2N particle the surface hardness increased to 1500HV and wear resistance also increased.

S.S.Akhtar et al. [33] have studied the AISI H13 tool steel which was heat treated by gas nitriding process. In industries dies were made up of AISI H13 tool steel used for hot aluminum extrusion and to enhance the life of dies they were heat treated with gas nitride under the controlled nitriding environment. Resulst showed that the die life improved by the application of gas nitriding treatment. K. Ali et al. [34] have studied the attenuation of heat treated S55c carbon steel which was measured by ultrasonic test. Annealing, tempering and quenching heat treatment processes were done on S55c carbon steel and its effects in attenuation was measured on UT (ultrasonic test). Specimen was quenched in oil & sea water medium. Double crystal with zero degree Celsius and 4Hz frequency were used in measurements. The results exhibited that after annealing, tempering & quenching process the material attenuation was decreased.

S. S. Hassain et al. [35] has studied the effect of heat treatment on AISI 1020 steel. To enhanced mechanical and physical properties, steel was heat treated by annealing, normalizing and hardening process. In this paper, hardening treatment of hypo-eutectoid steel sample was done at 30° C-50° C above the upper critical temperature. Steel was heat treated in furnaces, holded and then cooled in air, ash and water. A comparative analysis of hardness value of steel was done before and after heat treatment of the samples. The result showed that the highest value of hardness and low ductility was obtained from hardened treated sample and low hardness and high ductility were obtained from annealing treated sample. Moderate hardness and ductility were observed for normalizing treated sample.

K. Kamei et al. [36] aimed to increase impact toughness of thermally heat treated EN31 and studied its effects. Charpy impact test was used to check the impact toughness of thermal treated EN31. Annealing, hardening, tempering were performed on EN31 in electric furnaces and their effects were tested. Results of this research work exhibited that the hardness dimensional measurement, retained austenite to martensite were increased by the cryogenic treatment and the value of residual stress reduced. E.D.Doyle et al. [37] have studied about the nitride heat treatment on high speed steel (HSS). This paper explained that the embrittlement was avoided by limit the diffusion zone depth from the cutting edge of cutting tool (which was made up from nitride treated high speed steel). This could achieved by reduce the formation of compound layer with low time and temperature of nitride heat treatment. Result demonstrated that there was a benefit in compound layer generation with low tribological properties of friction with the application of heat treatment.

A. Grill et al. [38] investigated on AISI M2 tool steel which was nitride heat treated in R.F. inductive plasma (radio frequency inductive plasma). At 10 mbar pressure the plasma was stayed in mixture of N_2 & H_2 in a generator with 27.12 MHz's and the ion nitride was performed at temperature of 450° C -500° C with 400 W powers. It was noticed from the results that nitride phases were formed in plasma of pure N_2 and it was studied by X-ray diffraction. Ion nitride resulted that the hardness of surface was increased from 290 kgf mm^{-1} of untreated specimens to 1200 kgf mm^{-1} of treated specimen in 1:1 of N_2: H_2 gas mixture. M.A. DANG – Shen et al. [39] researched on H13ESR tool steel treated by thermal homogenization and its effect on impact toughness and microstructure. Annealing, oil quenching and tempering were performed on H13 ESR steel. From results it was observed that the spacing of dendrite arms became increased slowly from surface to center due to diffusion treated ingot at high temperature, in the area of interdendritic serration there was primary carbide particles of long size, remove the banded segration and uniform annealed structure and also refined the isotropic properties. Transverse direction impact toughness was improved.

S. Harish et al. [40] have studied the deep cryogenic treatment and shallow cryogenic treatment effects on EN31 bearing steel. Highest value of hardness of EN31 steel was achieved by cryogenic treated specimen as compared to conventional treated specimen. SEM (scanning electron microscope) was used to test the fractrography of cryogenically treated EN 31 steel and SEM images showed the appearance of equiaxed dimples and flat facets in shallow cryogenic treated EN31 steel. Micro cracks and large size dimples were found in deep cryogenic treated steel. A comparative investigation between thermal treated tool steel and untreated tool steel and their effects on its mechanical properties were studied by D. M. Sandhi et al. [41]. S7 & M1 were cryogenically and conventionally heat treated to increase metal wear resistivity and durability. Cryogenic treatment was used and its main aim was to transform the retained austenite into martensite and because of this, metal properties was enhanced. At austenite temperature, metal was conventionally heat treated, similarly at 84° C metal was shallow cryogenic treated for 8 hours & at 196° C metal was deep cryogenic treated for 24 hours. Behavior of carbide improved when cryogenic treatment increases the martensite decomposition.

AISI S7 tool steel was heat treated by vacuum carburizing at 950° C and 1000° C and its effects were studied by Liu – Ho Chiu et al. [42]. This vacuum carburized treated specimen was further quenched in gas medium and also tempered at different temperature. It was observed that when tempering temperature of carburized specimen undergoes low, then the quenched specimen which was carburized at 1000° C had low surface hardness than the quenched specimen carburized at 950° C, because of the retained austenite presents in a large amount at 1000° C carburized specimen. It is also noticed from the results that when the tempered temperature of carburized specimen goes high, then the surface hardness of specimen was higher at 1000° C in comparison to the carburized specimen at 950° C. The other important observation was that when the temper range of specimen was lies in between 450° C -550° C then the carburized specimen had modest increased surface hardness because of the effect of secondary hardening.

C. Padmavathi et al. [43] have studied the properties and sintering behavior of Al-Mg-Si-Cu alloys after the conventional and microwave heat treatment. At 570° C, 590° C, 610° C and 630° C, the alloys sample were consolidated in the furnace of microwave and conventional under vacuum condition. An improvement of about 58% in process time was achieved by microwave heat treatment process in comparison of conventional heat treatment with the high rate of heating. At the boundary of grain, large melt fraction with inhomogeneous microstructure was observed due to rapid heating. Because of less diffusion time, the absence of intermetallic was produced and it was observed with the help of XRD. At 630° C the alloy compact was sintered which resulted in the 41% improvement in ductility, 27% increase in ultimate tensile strength and 57% increment in tensile resistant strength.

S. Singh et al. [44] presented a review paper on various materials which was heat treated by microwave and their application in manufacturing sector. The main objective of this review was to reduce manufacturing cost, time and to increase the properties of product. Microwave process was applied on many various materials like: - alloys, metals, ceramics, coating etc. and from the result it was found that the material which was processed by microwave gave good mechanical properties as compared to conventional treated materials. The other important observation was that in comparison to conventional process, the microwave processed material took less energy/power with the reduced defects.

III. CONCLUSIONS AND FUTURE SCOPE

As per the literature review, it can be concluded that the conventional heat treatment process enhances the properties like: - hardness, toughness, strength, ductility, brittleness, microstructure refinement etc. of metals and alloys but a lot of time is required for heat treatment and these processes also consumes a lot of energy/power. This consumption of power and time can be reduced by the use of non-conventional heat treatment like microwave heat treatment & cryogenic heat treatment. The uniform or evenly heating of metal & alloy can be done by microwave heat treatment which can't be obtained from the conventional heat treatment process. Apart from this microwave heat treatment process also reduces the chances of crack generation in metals during the heat treatment.

A lot of scope with the novel type of heat treatment processes is available for the researchers. Presently a limited research work is available on the microwave heat treatment of the metal and alloys. Microwave heat treatment at the different range of the temperatures along with the various quenching media on the various metals and alloys can be attempted and studied further by the researchers.

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