QUENCHING A SIGNIFICANT INDEX CONTROL IN HEAT TREATMENT – AN OVERVIEW

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Abstract
The use of metals in this present age has increased greatly, the metals that were used in the past in different industries such as the automobile or construction industry were metals that are heavy and expensive but there’s been a rapid shift from that to lightweight metals that are less expensive and also have super strength due to the increased material properties such as ductility, hardness, wear resistance etc. Increasing the properties of metal is achievable by subjecting it to heat treatment, which helps in obtaining desirable properties. Quenching is known to be rapid cooling process for heated metals and it has significant effects on mechanical property, phase crystals location and structural analysis. This overview revealed the significant index control in heat treatment of a metal.

Keywords: Quenching, Heat treatment, Control, Metals, Index, Medium

1.0 Introduction

Heating materials such as steel, aluminum etc., leads to increase in volume, length and surface area, steel is mostly used because of the ability to easily alter some of its properties through heat treatment and changes in chemical composition [1]. During heat treatment, metals or alloys are heated at high temperature to a desired shape and the properties of the metal are enhanced and impurities removed during this process, also it should be noted that heat treatment is necessary for any metal that has been heated to certain degree, this has to be done properly in order avoid cracks and propagation in the metal [2]. This process of heating and cooling has great effect on changes in different properties of the metal. The grain structure of the material is refined i.e. softened after heating a metal, this makes the easy to work and shape i.e. there is an increase in the ductility which is essential important for all industries as it can therefore be molded to the desired shape [3]. According to Šolić, et al., [4] the properties and microstructure of a metal is greatly affected by heat treatment and it also has an impact on the dimensional control and residual stresses of steel. The use of inappropriate heat treatment is majorly responsible for the problems encountered during the treatment of part other factors responsible for this are defective parts, poorly designed part and making use of steel grades that are not correct. Some practices in heat treatment are regarded as inappropriate due to their negative impact on the metal, they include practices like burning, overheating, using austenitizing temperature non uniform heating and inappropriate quenching [5]. Heat treatment can be done using several methods such as hardening, case hardening, tempering, annealing, and normalizing [6]. One of
the heat treatment method used to change the physical characteristics of metal by making the metal more ductile, soft, and tough is annealing. The change in physical characteristic depends creating a weaker microstructure or releasing the residual stresses in metal. Therefore, in order to strengthen a metal part heat treatment techniques are very useful. It is also observed that solidification is gotten from subsequent cooling and from the heat treatment cycle, for instance in average to high carbon steel austenite is generated from martensite. This type of quenching is done by inserting hot metal in a quenching process [6].

For the purpose of this review we shall be focusing on quenching and the medium used during quenching process. The rapid cooling of heated metal to enhance certain properties is defined as quenching, this rapid cooling is carried out in different media and the medium used determines the cooling rate and the microstructural properties of the heated metal. The mainly used quenching media are water, oil, brine, and caustic [7,8]. Temperatures above 700°C are considered to be at a critical, cooling metal at this temperature creates a Leiden frost effect which makes the quench medium, for instance water form a bubble like shape and float on the hot surface and moves randomly as it cools it off [9]. In this review the following metals are taken into consideration because of the consumption rate and easy to work, they are steel, aluminum, different alloys. Also different properties such as malleability, ductility, toughness etc. were considered as well.

2.0 Scope and its Applications

The discovery and commercialization of steel played an important role in the recent civilization dating as far back as hundreds of years ago. Steel is basically a combination of iron and carbon and other additional elements; it was an important asset during the mass production industrial era and still is today in this present industry 4.0 era. Steel can be gotten easily and it is not expensive to buy [10]. Application of steel can be found in different products like domestic appliances (spoon, plate, pot), materials used in construction, automobile part. Improving certain mechanical characteristic of steel such as yield strength, ductility and hardness can be achieved by refining the grain size [11]. Knowing the difference between grain size and deformation helps in determining how steel behaves when they are under different working conditions. It has been observed from recent studies that the demand for steel that are lightweight with high mechanical properties has increased greatly amongst the aircraft and automobile industry. Increasing the carbon content of the steel can help in achieving the desirable mechanical properties and this is done by heat treatment [12].

Industries have moved from the use of heavy and costly metal to lighter and cost effective metals like low cost aluminum alloys, this has been on the sharp increase for the past two decades as manufacturers want to maximize profit in the best way possible and also produce environmental friendly materials that are easily recyclable [13]. The demand for aluminum alloys is on the increase because of the excellent properties it possesses coupled with its impressive strength to weight ratio which makes it much lighter and also increases the overall fuel efficiency [14]. One of the important methods that can be used to improve the mechanical characteristic of an aluminum alloy is heat treatment, which has an important influence on the final design of the product [15].

According to Srinivasan, et al., [13] the required method for strengthening of alloy is usually carried by precipitating hardening that includes certain heat treatment procedure preceded by aged treatment at a temperature of given intervals. Quenching by direct immersions is widely used compared to other quenching methods and this is done to avoid cracking and distortion by
reducing the formation of unwanted transformational and thermal gradient. In a situation like this, water is frequently used for quenching by immersion because its accessibility and unique property [16]. Cui, et al. [17] stated that because of the superb properties of high quality, low thickness and great erosion opposition, the high-quality 7075 aluminum compound sheet is generally utilized in the flight and car businesses. For the last item great mechanical properties, heat treatment and maturing treatment of aluminum compound sheets is necessary[16]. The mechanical properties rely upon the microstructure which is influenced by the historical backdrop of temperature. The investigation of temperature variety in the heat treatment of aluminum compounds is along these lines an essential for the improvement of the microstructure and the accomplishment of great mechanical properties [17].

In order to adjust the microstructure and characteristic of the aluminum alloy piece, the immersion quenching process is commonly used [19]. Water was used for quenching due to its excellent coolant ability and availability to reserve the microstructure in solution treatment. Four boiling schemes with surface super heat rise can be further used to separate pool boiling, they are: (1) Transition boiling (2) unrestricted convection cooling; (3) nucleate sizzling; (4) stable sizzling of the film. Pool boiling is therefore slightly different from cooling by immersion quenching[20].

Generally the film boiling regime takes place when the heated metal is at a temperature beyond the Leiden Frost limit, and because of this phenomenon known as the Leiden Frost effect a vapor film is created on the heated metal during the quenching process. Thermal radiation was said to have occurred between the quenching medium and the heated metal surface during the film boiling process. Because of the vapor layer acting as a separator, the change of temperature rate is relatively low [17]. When the temperature dips under the Leiden ice Point edge when steam layers breakdown, at that point the cooling procedure all the while enters the change bubbling stage [20]. When the vapor falls, the recovery phenomenon occurs with increasing contact between solid and liquid products. The heat transfer rate is therefore different in the transitional boiling phase than in film boiling phase [21].

Tsuboyama et al.[22] discovered that the heat transfer between metal and liquid is greater at the boiling stage than at the boiling stage of film. They demonstrated that the dormant heat devoured by the liquid in the stage change and the confined deterioration of the liquid at the interface were credited to the high cooling rate. The vapor film diminishes and the air pocket instates as the temperature drops. The way toward cooling has entered a nucleate bubbling stage, which, as indicated by the examination by the strong surface comes in contact completely with the fluid [13]. The sub-cooled liquid starts to bubble quickly when the fluid comes into contact with the heated surface. The rate at which heat is moved between the metal and fluid is very high and therefore causes the heated metal to cool very quickly [15].

Finally, when the heated metal temperatures fall beneath the boiling state of the fluid, a convective cooling system is established. Tensi et al. [6] state that at lower level cooling degree becomes steady. Qualitative research on physical phenomena during the quenching process has been carried out, providing reasonable mechanisms to resolve the variation in metal's temperature during the quenching process. According to Šolić, et al., [4] overheating takes place when low-alloy steels are heated for a long period to a temperature higher than 1200°C before hot working, due to heating and preheating at high temperatures the formation of MnS particle in austenite occurs as a result of this phenomenon. There is notable increase in temperature, and while cooling the following reprecipitation occurs at different intervals on the austenite grain with α-MnS particles in very
fine array. The intergranular sulphides network can offer a favored, low dynamism rupture trail in comparison to a regular trans-granular rupture path during the next heat treatment. Anything that causes excessive stress while quenching can lead to cracking [21]. Cracks during quenching is mainly intergranular and this may be associated with certain factors, which also lead to intergranular fractures in overheated steel. This result to a reduction in the mechanical properties of the room temperature (especially ductility, strength of impact and toughness). The presence of matt intergranular side on the ordinary flexible crack of an effect example is connected to the decreased mechanical properties. It is seen that overheating can be turned around in heat influenced territories of steel castings, weld, and vigorously ground part (as a result of a distinction in the pouring temperature and the adequacy of the restrictive grain inoculants utilized in the form surface) [22].

When a low-alloy steel is heated way above the overheating temperature higher than 1400°C, the process is called burning. The austenite grain borders are the outcome of the separation of phosphate, Sulphur, and carbon at this temperature [23]. The following heat treatment provides extremely poor strength of impact and almost entirely inter granular fracture after failure of impact. Forging tends to break easily while cooling or going through further heat treatment if burning takes place while forging. The main issue with burning and overheating is that they may not be noticed till subseuent heat treatment, although they usually occur during forging or rolling [25].

3.0 Deformation Resultant Effect of Quenching

Because of their profoundly explicit quality and superb mechanical attributes, 7000 arrangement aluminum combinations were broadly utilized as segments of the structure of airplane and vehicles [26]. Be that as it may, one of the fundamental purposes behind the broad utilization of the 7000 arrangement of high-quality aluminum compounds is the attractive hot functionality influenced by the strain rate and temperature twisting [27]. Thusly, for architects of metal shaping procedures (hot expulsion, producing and moving) with great comprehension of the conduct of high-quality aluminum combinations in hot distortion conditions is significant [28].

A few specialists have recently researched the heat twisting conduct of 7000 arrangement aluminum amalgams. As per the handling map for 7075 aluminum composite, accomplished ideal hot working parameters and the zones of stream shakiness. Girelli et al., [29] examined the impacts of weight on dispersal productivity, shakiness parameters, preparing maps and microstructural development of aluminum composite 7075, and found that specific sorts of shaky transition sign are observed during a hot deformation with an increased strain, such as adiabatic screening bands or flow locations. Zheng [30] investigated the properties of microstructure of aluminum alloy 7050. Results show that a 7050 alloy softener is not delicate to stress, the principal softing machinery with a loading degree of 0.1 s−1 is an active retrieval of 7050 alloy at 340, 380 and 420 °C deformed [31]. The main alloy smoothing mechanism, which is deformed with 460 °C and various stress rates, is dynamic reclining. Although much research has been carried out on the behavior of the 7000 sequences aluminum alloy hot deformation, there is low research concentrating in the condition of quenching on the distortion features of 7005 aluminum alloy[32]. The purpose of this work is to assess flow stress behavior with regard to stress speed and sensitivities in deformation temperature, create a component equation to describe flow stress's dependence on stress degree also temperature, and create processing plans to enhance hot work limits for a drenched 7005 alloy. The reduction in weight can reduce energy consumption directly in the automotive and aircraft industries, which is
helpful for improving the fuel economy and the environment [33]. A reduction in the mass of a conventional vehicle by 10% means that fuel consumption will automatically go down by 6% to 8% without compromising the performance of the vehicle. The use of high strength steel and low-density sheets are two viable ways to reduce the weight of automotive structures [34]. Original equipment manufacturers that are into automotive panel parts found heat treatable aluminum alloys with high strength useful for production [35].

However, high strength alloys of steel and aluminum have low formability at room temperature, resulting in a high spring back and formed parts that are of poor surface quality, also the current use of such materials is limited by their lack of ductility with cold stamping [4]. In order to deal with this problem, processes of forming at high temperatures such as, hot gas forming, and incremental forming, superplastic forming, and hot stamping, are viable results to enhance the form intricacy and dimensional precision of formable portions. Hot or warm stamping by using solid dies can be used in the auto motive industry for the production of intricate panel mechanisms in high volume owed to its related high output[36].

Hot Form Quench has been introduced to produce heat-treatable high strength aluminum alloys with complex shapes among the hot stamping techniques, it is a new patented heat stamping method [9]. The blank is heat treated during a hot form quench, so that precipitates and inclusions can be dissolved to achieve a ductile microstructure. The blank is then transferred quickly to a press, stamped and quenched instantly using cold die at the same time. The process of artificial aging is used to enhance the strength of components for aluminum alloys that are heat-treated [37]. Rigorous research was conducted experimentally and numerically on the formability of hot form quench for diverse alloys.

Adetunji et al. [38] uncovered that flexibility increments and the flow stresses decline with the expanded temperature and further checked the impact of temperature on pliability at a uniaxial load for a more extensive variation from 250 °C through 535 °C. All things considered, uniaxial pliability isn't adequate to evaluate the formability of the complex strain course during useful shaping exercises. Shao et al.[3] tried the AA6082 forming breaking point bends under HFQ conditions and brought up that as far as possible expanded as the temperature rose and the strain rate decreased[21]. Formability can estimate just the extraordinary feeling of anxiety, meanwhile the success of part forming should also take into consideration the deformation uniformity determined by stress and stress rate hardening[16].

4.0 Different Technologies used in quenching

The optimum uniformity of the quenching process is crucial to minimize cracking, distortion, residual stress and spotting hardness. The design of the quenching system is one of the major influences of quenching uniformity [12]. System design shortcomings have often been dealt with insufficiently by both suppliers of equipment and heat treatment technicians, often with disastrous results. There are basically no industrial guidelines for Quench system design except few - known organization details. In this way, the cutting edge structure criteria to assist the specialist with designing and assemble an extinguishing framework that will give ideal heat transfer and quench consistency are not widely gathered [22]

Unsettling is one of framework plan's basic zones. The combined impact of disturbance on the exhibition of various quenching oil has been inspected in detail.
Tsuboyama [20] reported that AISI 4135 steel was able to thrive on conventional quenching oil with increasing agitation. Though a decrease in oil temperature improved the durability, it was significantly lower than the exponentially increasing rate of agitation [24]. Beck et al. [9] also demonstrated that increased rate of agitation led to an increase cooling rates and the hardening capacity for SNCM 21 steel of both oil and water quenchant. Vivas and Tardio [26] investigated the impact of temperature and agitation on distortion of different carburised steels. Moreaux et al. have studied the comparative effectiveness of absorption and spray quenching using an aqueous polymer and mineral oil quenchant. It was observed from the result that increase in depth of hardness occurs as a result of increased agitation. Moreaux et al. demonstrated that for the portion of the component under greatest agitation, the as-quenching hardness of a complex component that was settled in either aqueous polymers or mineral oil [22].

The black hole of heat treatment is often called quenching, there is little understanding of the quenching process itself in many thermal treatment companies [17]. Many recent publications have interrelated several key principles used while quenching such as physical chemical phenomenon, surface wetting, and heat transfer with metallurgical properties such as hardness and distortion derived from quenching [13]. The seriousness of Quench depends on agitation. The magnitude and turbulence of the fluid flow around a section is however essential compared to the uniformity of the heat transfer during the entire quenching process [12].

In a quench tank the resultant effect of fluid flow in a non-uniform manner around the quench area is one of the major contributing factors to increase in thermal stress, non-uniform hardness, cracking and distortion[29]. It is crucial that the fluid flow in the quenching area is optimized to minimize cracks and control the distortion. There are traditional ways of measuring fluid flow for laboratory and commercial purposes, which include: magnetic flow meter, pitot probe and hot fil anemometer [29]. Nevertheless, these methods are usually ineffective to monitor continuous fluid flows in commercial quenching tanks during heat treatment and while they provide extremely valuable perspective into the fluid mechanics of the quenching process, their value from a design and simulation perspective is limited [33]. Computational fluid dynamics modelling is increasingly being used to assess fluid flow uniformity in a quenching tank. CFD modeling was carried out on a traditional laboratory apparatus for analysis of cooling curves. The results showed that even this system was vulnerable to significant fluctuation in the quenching zone, which leads to significant changes in the results of cooling curves. The main advantage of computational fluid dynamics analysis is that there is no need to create a prototype system before carrying out system analysis [34].

Srinivasan et al. [13] outlined a recent modeling process designed to simulate a dip quench cooling procedure utilizing the AVL - FIRE business code. The way toward boiling stage change is driven by the plunging of the hot strong into a fluid shower that is subcooled and the subsequent two stage stream is dealt with by the two liquid Eulerian technique [38]. The mass exchange impacts are demonstrated by different bubbling strategies, similar to the nucleate or film bubbling which are basic in the bubbling framework. The AVL code coupling interface (ACCI) highlight numerically unions separate computational areas worked for the fixed strong and a fluid (quenchant) space with the interface of strong – fluid limits. The progressed ACCI strategy empowers the stage change rates in the fluid space to show up as a cooling rate on the strong limits that are extinguished [35]. Therefore, with the improvement of temperatures in the strong area the multi-stage stream elements in the fluid space are taken care of in a firmly
connected way. The technique utilized in the AVL - FIRE exchange code is utilized to reproduce the extinguishing of strong parts. The present research approves stage - change models by reproducing extinguishing procedure of a workpiece which estimates different water temperatures from 293 to 353 K information that are accessible [36].

The counts give a nitty gritty portrayal at different occasions of the fields of vapor and temperature in the fluid and strong fields [37]. In particular, changes to the fluid vapor stream territory close to the strong interface are composed relying upon the bubbling mode. At various observing focuses and under various sub-cooling conditions, our models anticipated temperature history very well connects with test information any place accessible. When all is said in done, the new extinguishing model's predictive capacity is well demonstrated [38].

Conclusion

The direct impact of quenching during heat treatment is the change in physical or chemical characteristics of the metal to suit particular purpose and this often done to increase the strength, ductility and toughness in other for such metals to withstand severe conditions and have long lifespan. As discussed by several authors there are several means by which metal can be heat treated such as annealing, tempering, quenching and normalizing. This review focused quenching as a proper heat treatment that is widely used for deformation process that occurs during quenching.

Acknowledgements

We acknowledge the financial support offered by Covenant University in actualization of this research work for publication.

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