



Heat Treatment Method for H13- An Analysis of Carbon Diffusion

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Abstract— However, while being a small percentage of the total cost, heat treatment is perhaps the most important and critical factor in determining fabric quality. Under entirely varied circumstances and treatment lengths, a series of heat treatment tests were undertaken to examine the carbon diffusion in H13 steel during austenitization. Austenitization was investigated in four different ways; without part management, with stainless steel foil wrapped over it, and in a vacuum. Researchers found that chrome steel foil wrapping may prevent decarburization, leading to a persistent hardness profile similar to that of vacuum heat treatment. While these two heat treatment techniques have very similar tempering characteristics, they are fundamentally different. H13 steel has a carbon content independent of its layer thickness and hence hardness, according to results obtained from gas component samples.

Index Terms— Carburization, H13 tool steel Hardening, Heat treatment, Nitriding.

I. INTRODUCTION

Heat treatment is a procedure to adjust the metallurgical and mechanical properties for explicit purposes that includes warming and cooling of the material. It is realized that the hardness got from solidifying process is extraordinarily impacted the accessible carbon content in steel during extinguishing [1]. The nearness of carbon inside the steel lattice is to a great extent dependable to the possible mechanical properties, which makes the steel material an exceptionally valuable product of regular daily existence. It likewise influences both the base solidifying temperature and the greatest feasible hardness [2]. To build up a legitimate heat treatment climate for steel, there is a need to comprehend the connection between the

environment structure and the carbon substance of steel during the austenization time frame. Practical carbon dispersion model for the carbon profile is significant. Carbon can either diffuses out or into the steel network contingent upon the workplace [3]. In the event that decarburization occurs, the hardness on the outside of the rewarded material will be lower than anticipated. Be that as it may, if carburization was led, the rewarded material would be solidified [4]. Numerous explores have been led identified with the carburization procedure (e.g., [5–8]); in any case, understanding of the decarburization during heat treatment is as yet restricted, particularly for H13 apparatus steel. In spite of the fact that Arain [9] researched the contrast between the open air heat treatment furthermore, the vacuum heat treatment, his emphasis was basically on H13 durability conduct. The motor of the carbon dissemination inside the H13 device steel is additionally not yet clear. Along these lines, the primary goal of this exploration is to research how the encompassing condition during heat treatment process impacts the material hardness profile and to examine the carbon dispersion active when the material is exposed to distinctive barometrical conditions during austenitising

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stage. Tests of H13 steel would be exposed to warm treatment process with various term times and under various climatic conditions. Hardness profile of each example would then be investigated. It is additionally important to explore the viability of the gas nitriding process. The carbon dissemination motor of H13 steel during heat treatment will likewise be examined. Carbon dispersion process is displayed dependent on the Van-Ostrand-Dewey arrangement and the carbon actuation vitality and carbon diffusivity at 1020 °C is resolved.



Fig. 1 Pack carburization with stainless steel foil wrapping [5]

II. RESEARCH AND TESTING

The four distinctive heat treatment and air conditions researched in this investigation are heat treatment without environmental control, heat treatment with tempered steel foil wrapping, pack carburizing heat treatment, and vacuum heat treatment. Further treatment would likewise be directed to research the impact of carbon content on the proficiency of the nitriding case solidifying process. Subsequent to extinguishing, the examples were exposed to two hardening forms followed by gas nitriding. Between each procedure, an example was gathered for investigation. Table 1 sums up the test plan. The examples utilized in this examination have the size of 7mm× 10mm× 60mm with the underlying hardness of ~12HRC. For the warmth treatment without barometrical control, the examples were warmed in a suppress heater at austenitizing temperature of 1020 °C for the predetermined timeframe. The examples were situated at the inside locale of the suppress heater furthermore, were in direct contact with the encompassing air. For this barometrical condition, carbon in steel could openly respond with the encompassing air. An electrical warmed

open environment heater (mute heater) was utilized for all warmth treatment forms aside from vacuum heat treatment process. Information lumberjack with a thermocouple was utilized to screen and guarantee the correct treatment temperature was kept up during the procedure. In the warmth treatment with hardened steel foil wrapping, examples were completely wrapped with a bit of pure steel foil to diminish the pace of concoction dissemination between the example and the heater climate. This strategy is normally utilized in industry and the recommended wrapping strategies can be found in [10]. For this exploration, each example was first wrapped with the long side (the length) twofold collapsed, at that point twofold collapsed deep down from the other two closures (the widths). This analysis setting expected to limit the ceaseless carbon response and oxidation between the example what's more, the encompassing environment by the presence of treated steel foil. The tempered steel foil goes about as an obstruction to confine the carbon response between the example and the environmental factors. The test enclosed by tempered steel foil is appeared in Fig. 1a. In pack carburization heat treatment, a steel box holding an example was completely pressed with charcoal with case solidifying precious stone, barium salt, chemical formula of $Ba(ClO_3)_2$ and was warmed to a temperature of 1020 °C. The example is situated at the focal point of the steel box and is completely secured by barium salt, so every example surface is in contact with the equivalent carburized climate condition. A photograph of the pack carburization explore before the example is concealed with barium salt is given in Fig. 1b. The vacuum treatment was led in an A bar vacuum heater at rough 25 and preheated at temperature of 650 °C and 850 °C. Each preheating stage took 1h. At that point it was warmed up to 1040 °C and held for either 60, 90 or 120min, and at last cooled to room temperature in a pace of 30 °C/min.

When the austenitizing time is reached, the example must be quickly cooled from the austenite state to the room temperature to frame martensite. Two diverse

cooling techniques were applied with the initial three environmental conditions, i.e., fan cooling and water extinguishing. For the fan cooling, the examples were taken out from the heater and were cooled in front of a running fan. The examples were continued pivoting so the cooling rate would be even on all surfaces. In the water extinguishing, the examples were placed into a pool of water, and continued mixing in the water for 2min. Because of useful troubles, the vacuum heat rewarded tests were just cooled in the vacuum heater with 2 bar of nitrogen gas and the cooling pace of 30°C/min. After the cooling, the example measurements were estimated again to search for the size changes during the procedure. A little example with the size of 7mm× 10mm× 10mm was then cut from each extinguished examples for hardness test and metallographic examination. The rest of the piece of the examples would then be exposed to two treating forms which were held at temperature of 540 °C and 595 °C in a vacuum heater for 4h. To examine the elements of the carbon content on the proficiency of case solidifying by gas nitriding, the last part of the staying rewarded tests were cut into three distinct pieces and exposed to once, twice or threefold occasions of nitriding case solidifying process. Tests from pack carburization trial would not be exposed to case solidifying process since this is certifiably not a typical practice in industry. The gas nitriding process is led at 530 °C under controlled air for 6.5h.

III. DEMONSTRATING OF CARBON DISPERSION PROCESS

Austenization of H13 steel is constantly led at temperature inside 995–1040 °C. At such high handling temperature, carbon may diffuse into or out from the material relying upon the air condition and the handling temperature. This is urgent to material mechanical properties since carbon content has direct relationship with the material strength. Decarburization process happens when steel responds to the oxygen, wet or dry oxygen in the environment when it is warmed at 600 °C or above where the main impetus is the carbon synthetic

potential over the material and the air [9]. The most essential stoichiometric concoction response of carburization and decarburization is:



This concoction response is reversible, and the compound harmony consistent (K) can be characterized as [10]:

$$\log K = -\frac{8918}{T} + 9.1148 \quad (2)$$

Where, T is the temperature in Kelvin. Knowing the halfway weight of the carbon dioxide and the carbon monoxide, the balance weight percent of carbon on steel at the given handling temperature can be anticipated as follow [10]:

$$wt\% C = \frac{1}{Kfc} \frac{PCO^2}{PCO_2} \quad (3)$$

Where, PCO and PCO₂ are the halfway weight of their addendums, what's more, fc is the movement coefficient of carbon. Eq. (3) communicates the balance surface carbon content is represented by the working temperature since K is a component of temperature and the halfway weight of both the carbon dioxide and the carbon monoxide. fc for Fe–Cr–C composite framework can be determined utilizing this condition [10]:

$$\log fc = \frac{2300}{T} - 2.24 + \left(\frac{179}{T}\right) (wt\% C) - \left(\frac{102}{T} - 0.033\right) - 0.033 (wt\% Cr) \quad (4)$$

With Eqs. (2)– (4), the accompanying condition can be set up to appraise the warmth rewarding air for little alloying Fe–Cr–C steel framework.

$$\log \left(\frac{PCO^2}{PCO_2}\right) = \log (wt\% C) + \frac{179}{T} (wt\% C) - \left(\frac{102}{T} - 0.033\right) (wt\% Cr) - \frac{6618}{T} + 6.8 \quad (5)$$

Eq. (1) shows in carburization (option to left) response, the gas carbon monoxide in the climate breaks down on the steel surface into the beginning carbon and

carbon dioxide. This brings about higher carbon focus on a superficial level and a focus slope of carbon between the surface and the center of material. In light of the dispersion hypothesis, which will be portrayed a short time later, the carbon deteriorated on metal surface diffuses internal into the metal center until a harmony is reached, while the result carbon dioxide further responds with the carbonaceous material (if there is any) to produce new carbon monoxide. Decarburization (left to right) is an opposite procedure of Eq. (1) and works in inverse request of carburization. Carbon in steel responds with the oxygen noticeable all around to shape the carbon dioxide, which further responds with the carbon in steel and forms the carbon monoxide. The shaped carbon dioxide and carbon monoxide break to the surrounding environment through the pores and splits in the scale. Min et al. found the thickness of the oxidation film shaped during H13 oxidation increments with the preparing time and temperature. This is since the hematite shaped over the magnetite layer during the oxidation procedure lessens because of the low dissemination speed of the metal particle and oxygen in hematite stage.

In either carburization or decarburization, carbon moves from high fixation district into low focus area. This announcement doesn't mean carbon is just moving in one Course. In all actuality, carbon goes to any bearing at the same time, yet in normal, a net dissemination transition of carbon diffuses to bring down focus district from high fixation area.

For such dispersion process, Fick's Law can be utilized:

$$J = -D \frac{\partial C}{\partial x} \quad (6)$$

where, J is the dissemination motion per unit cross-segment territory per time, D is the dissemination coefficient, and $\partial C/\partial x$ is the focus slope. The diffusivity of a component can be resolved by the Arrhenius response condition:

$$D = D_0 \exp \left(- \frac{E}{RT} \right) \quad (7)$$



Fig. 2 – Furnaces used for heat treatment hardening experiments: (a) muffle furnace and (b) vacuum furnace.

Where, D is the dissemination coefficient, D_0 is the pre-exponential factor (cm^2/s), E is the actuation vitality for dispersion (J/mol), $R = 8.314 \text{ J/(mol K)}$ and T is the outright temperature in Kelvin. Eqs. (6) and (7) show that the dissemination motion is administered by the grouping of the diffusing species at any stage, dispersion temperature and the zone opposite to the dispersion bearing. Carbon diffusivity is moderately lower in apparatus steel than in other steel since it contains numerous carbide framing components (Cr, Mo and V) and the nearness of Si additionally decreases the level of carbon diffusivity. These outcomes in a similarly slim concentrated carburized layer. Kucera et al. watched that the dispersion rate increments with expanding temperature, it can likewise be impacted by substance piece, and the profundity of decarburized layer is expanded with time. It ought to be noticed that the Fick's

law can't be utilized for carburization/decarburization displaying, as the dispersion transition is changing with time and the focus slope is a component of time. So there is a requirement for the utilization of Fick's subsequent law, a subsequent subsidiary model used to portray the time transient dissemination process. Fick's subsequent law is:

$$\frac{\partial C_x}{\partial t} = - \frac{\partial}{\partial x} [-D \frac{\partial C_x}{\partial x}] = D \frac{\partial^2 C_x}{\partial x^2} \quad (8)$$

Where, C_x is the fixation at separation x from a reference

Point and t are the time. The normal carbon diffusivity (cm^2/s) for most steel can be approximated by [16]:

$$D^2c = 0.12 \times \exp\left(-\frac{16000}{T}\right) \quad (9)$$

With the accompanying limit condition: at $t = 0$, surface fixation is equivalent to the encompassing focus, and considering the material is interminably long, the fixation on the opposite side (away from the surface) is equivalent to the underlying concentration, so Van-Ostrand-Dewey solution to the Fick's second law diffusion equation is defined as follow:

$$\frac{C_x - C_s}{C_o - C_s} = \text{erf}\left(\frac{X}{2\sqrt{Dt}}\right) \quad (10)$$

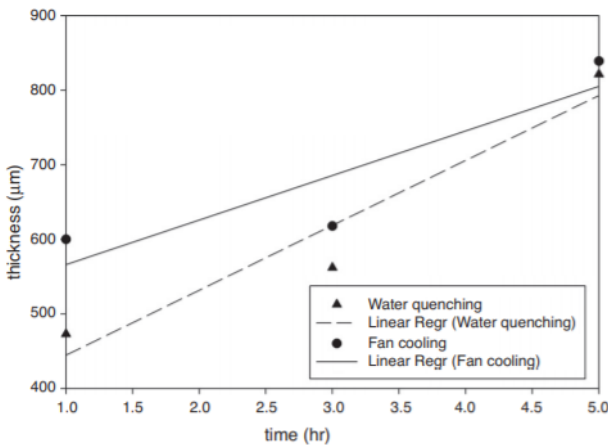


Fig. 3 – Graph of decarburization layer thickness in het a treatment without atmospheric control.

In Fig. 4, a comparison is made between the experimental value of a 1020 C heat treatment followed by fan cooling and the theoretical model. It is the space between the point where carbon content drops and where it reaches its starting level that is referred to as the overall depth of decarburization. Despite this, it is difficult to identify owing to its asymptotic nature, and it has little impact on the market as a whole. In this case, the decarburization depth utilized is the effective decarburization depth as a result, it is defined as the distance between two surfaces at a carbon content of 0.9%..

Without the use of specific equipment, it is difficult to determine the carbon content profile for this research. Decarburization depth was instead determined using the 2HRC core hardness as a reference. A 56HRC average core hardness means the effective decarburization depth is 54HRC. In the heat treatment business, a value of 2HRC is considered acceptable. Using this method, it is possible to build a connection between treatment time and decarburization layer thickness Figure 3 shows this. A decarburization layer thickness of 0.550mm is obtained after two hours of uncontrolled environment heat treatment. The graph in Figure 3 shows that the linearization does not cross the graph's origin. As a result, decarburization is controlled by two concurrent processes: surface activity and carbon diffusion. The carbon profile may be modelled using the Van-Ostrand-Dewey solution (Eq.10).

$$C_x = C_s + \text{erf}\left(\frac{X}{2\sqrt{Dt}}\right) \times (C_o - C_s) \quad (11)$$

H13 steel carbon diffusivity is not well known and no prior publications have been able to offer a value for it. Therefore, it is necessary to calculate the carbon diffusivity using experimental results. We assume that carbon content has no effect on diffusivity in this study. Combining Equation (7) with Equation (11) transforms it into Equation (12).

$$C_x = C_s + \text{erf}\left(\frac{X}{2\sqrt{[D_0 \exp(-E / RT)]t}}\right) \times (C_o - C_s) \quad (12)$$

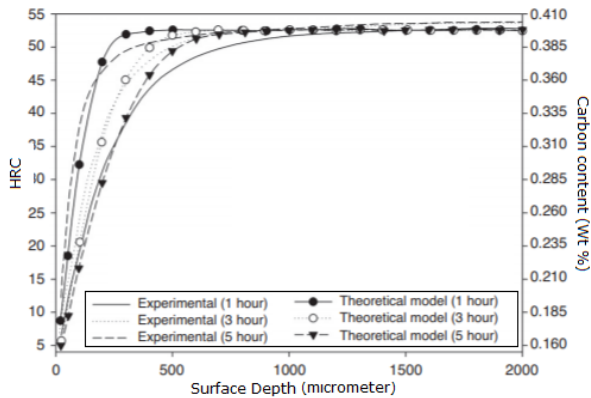


Fig. 4 – Comparison between the experimental value of heat treatment without atmospheric control at 1020 °C followed by fan cooling and theoretical model [5]

IV. RESULTS AND DISCUSSIONS

Figure 5 show the hardness profile for all examples heat rewarded without barometrical control and the hardness abatement can be found towards the surface district of all examples. The hardness at the area of 100m underneath the surface increments dynamically, at that point the hardness gradually increments towards the steady state. From the figures, it tends to be seen that there is impact on the material center hardness by the cooling technique. The diagrams show that tests cooled by water by and large have higher hardness (54–57HRC) than tests cooled by fan air (53–54HRC). The decarburized layer is found to be thicker as treatment time increases. Another notable difference is that the surface hardness (20m below the sample surface) of the fan cooled samples is lower than those quenched by water. The fan cooled samples had a surface hardness of 2–10 HRC while the water-quenched samples had a surface hardness of 14–22HRC. The fan cooled examples had hardness increment after the first treating stage while water extinguished examples don't show any hardness increment. Nonetheless, after the subsequent treating stage, the hardness of both fan cooled tests and water extinguished examples dropped to around 46–48HRC. Note that the treating procedure doesn't seem to have any impact on the decarburising zone. The hardness profiles of the examples heat rewarded with the treated steel foil wrapping. Such warmth treatment technique brings about a sensibly consistent hardness profiles all through the

profundity of the examples. The treatment time didn't appear to have any immediate impact on the hardness profiles. The outcomes additionally show that a slight drop in the hardness can be found around 20m from the surface. It very well may be seen that the principal treating process diminishes the hardness of the as extinguished examples from a normal of 59HRC to 57HRC, while the subsequent hardening process further diminishes the hardness to around 48–50HRC. From the outcomes appeared in Figures. 6 and 7, all the example countered a solidifying impact on a superficial level in the wake of extinguishing. Past the carburized layer, the hardness of all stuffed carburized tests was roughly the equivalent. It must be seen that the hardness at the area of 500–1000m from the surface was equivalently lower than its center hardness for the example heat rewarded for 1h.

This distinction doesn't show in tests heat rewarded for 3 and 5h. By considering the hardness profile of the surface area up to 500m from the edges, it can be considered that to be the treatment time becomes longer, the surface hardness increments, individually. The charts additionally show that tests cooled by water in truth have lower surface hardness than tests cooled by fan. Hardness increment can be found in the carburized tests cooled by fan after the main hardening stage. The improvement in hardness after the principal hardening process is particularly noteworthy at the focal area of the test and was expanded from 56HRC to 58HRC. The second treating stage doesn't show any impact on the hardness.

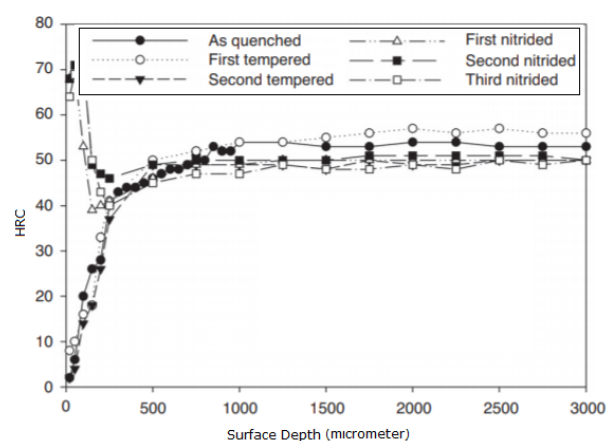


Fig. 5 Fan cooling and gas nitriding hardness profiles of materials heated without ambient control at 1020°C [5]

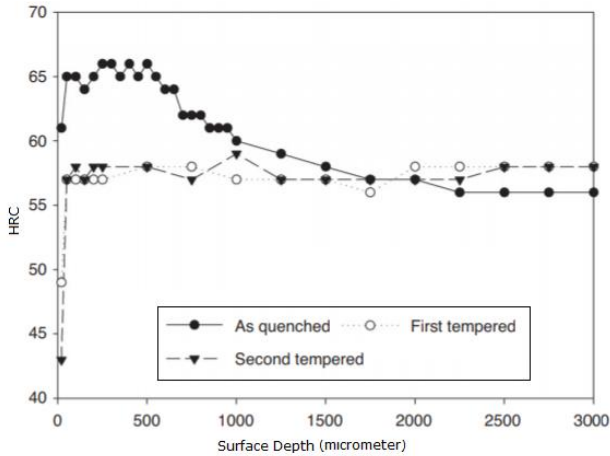


Fig. 6 – Profile of hardness after heat treatment at 1020 C followed by fan cooling of pack carburized samples [5]

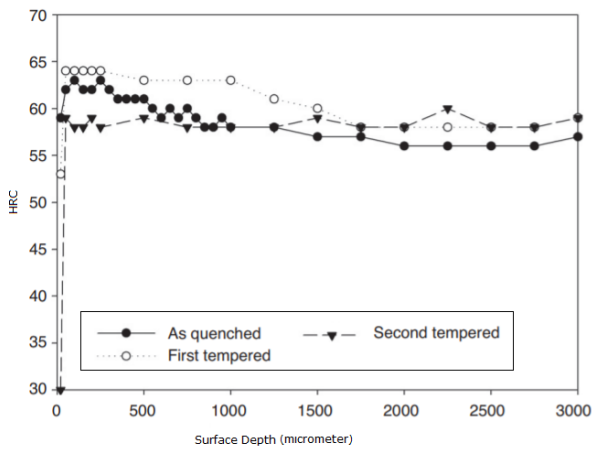


Fig. 7 – Profile of hardness after 1020 C pack carburized heat treated samples were water quenched [5]

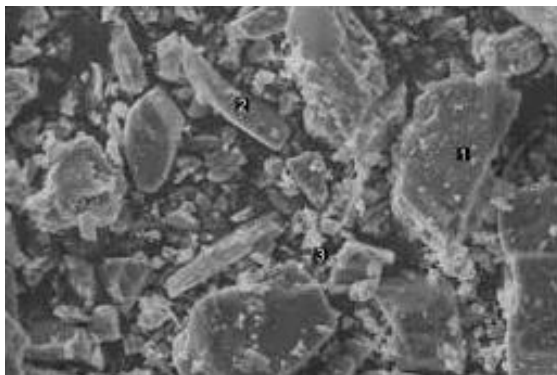


Fig. 8 – First tempering heat treatment of the sample in the vacuum furnace

In any case, if the carburized tests were cooled by water, after the main treating stage, auxiliary solidifying impact can be found all through the examples and is particularly prevailing at the surface area. Extraordinary measure of hardness improvement can be found at 1000m

underneath the surface. After the subsequent hardening process, the hardness profile got steady with the hardness around 59HRC like the center hardness of the principal tempered condition.

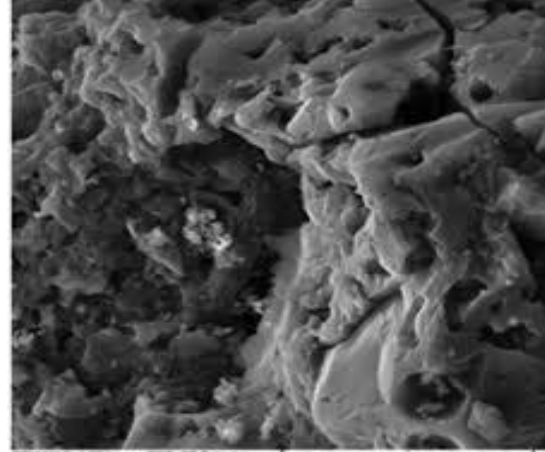


Fig. 9 – The quenched state and the third nitride state are shown in the micrographs

As appeared in Fig. 8, there is no sign proposing the time of warmth treatment has critical impact on the hardness of the as extinguished examples in vacuum heater and all as extinguished examples have a comparative hardness level. No decarburization or carburization layers are found and the hardness differs a couple of scale focuses around 57HRC. It very well may be seen that if the treatment span builds the degree of hardness variety is lower. The charts shows that even with a decarburized layer, the nitriding procedure can even now expand the surface hardness altogether up to a specific profundity from the surface. With the exception of the third nitriding process, the first and the second nitriding forms bring about hardness upgrades after the nitriding process. With expanding heat treatment length, the surface hardness (20m underneath the surface) became lower, individually. Be that as it may, the surface hardness was expanded with the hours of the nitriding procedure.

After the nitriding process, the hardness at district 500m from the surface expanded drastically. The solidified surface layer gets thicker as more gas nitriding forms are led and the hardness beneath the solidified layer remains a similar level as the hardness of the second

tempered condition. Results have demonstrated that both vacuum heat treatment and heat treatment with hardened steel foil wrapping produce a sensibly steady hardness profile on the as extinguished examples. This proposes the carbon neither diffuses into or out from metal framework during austenitization. This is sensible for treatment in vacuum heater as the carburization can't be started because of the nonappearance of carbon monoxide. For the heat treatment with the hardened steel foil wrapping without ceaseless flexibility of the carbon dioxide, it is accepted the examples were in decarburization state during austenitization. This can be bolstered by the drop in hardness at 20m underneath the examples surface. Nonetheless, with the unimportant measure of the carbon dioxide inside the wrapping, the decarburization process arrives at balance after a brief timeframe. Albeit both the vacuum heat treatment and the foil wrapping heat treatment can forestall the decarburization procedure, they show distinctive hardening qualities. In the vacuum heat treatment process, optional solidifying can be found after the main temper stage and between the treating temperature of 500 °C and 550 °C. This optional solidifying impact is the fourth phase of the treating procedure. From the micrographs appeared in Fig. 9, it tends to be seen that the examples after the primary treating process are filled with martensite. For every individual warmth treatment technique, if the hardness profiles of the nitrided tests are contrasted and the hardness profile of their second tempered express, the hardness profile past the nitrided layer is like one another. Through these outcomes, it demonstrates the gas nitriding process doesn't change the microstructure other than inside the nitrided area. This can be upheld by the micrographs images. These micrographs show the examination between the as extinguished state and the nitrided state for the tests heat rewarded without climate control. The micrographs show the gas nitriding process present the solidify layer inside the decarburized layer by giving nitrogen to diffuse access to the center area and modify the surface creation

[10], anyway the compound layer can't be found on a superficial level. The outcomes propose the gas nitriding itself doesn't have any direct effect on the hardness profile of the internal piece of the tests. It is on the grounds that past the nitrided zone, the hardness profile intently coordinates the hardness profile of the particular second tempered condition. From this, it shows the benefit of utilizing vacuum heater over the suppress heater. It is in such a case that the nitrided layer doesn't cover the decarburizing zone, there is a huge hardness dip under the nitride layer, which can result in mechanical failure. This is a reasonable case particularly for the warmth treatment of aluminum expulsion bite the dust and is on the grounds that the suggested thickness of the nitriding layer isn't more than 0.3mm. Anyway, the trials show even 1h of warmth treatment without environmental control gives a decarburization layer thickness of ~0.5mm. In this way, there is consistently an impressive profundity of decarburization layer underneath the nitrided layer. It should likewise be noticed that the thickness of the nitrided layer isn't straightforwardly corresponding to the number of the gas nitriding process being directed. After second occasions of gas nitriding process, further case solidifying process doesn't appear to give any hardness improvement.

V. CONCLUSIONS

In the investigation of the carbon dispersion in H13 steel during austenitization, a progression of warmth treatment tests had been directed under various climatic conditions and length of treatment. The carbon development during austenitization of H13 instrument steel in the surface district is absolutely subject to the surrounding environmental condition. At austenitising temperature of 1020 °C, without consistent gracefulness of carbon dioxide, carbon particles in steel will in general respond with carbon dioxide in the layer of the iron oxide and getaway to the air. This is the decarburization procedure and is appeared by the warmth treatment without air control tests. In any case, the decarburization

procedure can be confined by either restricting the flexibility of carbon dioxide, or austenizing the material in a vacuum domain. With tempered steel foil wrapping, tests had the option to keep up their carbon during the warmth treatment procedure and produce a genuinely steady hardness profile like that of the examples heat rewarded in vacuum heater. In the pack carburization tests, the carbon monoxide was provided persistently from the encompassing charcoal and caused an expansion in the carbon deterioration in the surface and subsequently, an increment of hardness. Despite the fact that each warmth treatment condition brought about an alternate hardness profile, it didn't influence the outcomes for the gas nitriding. All examples exposed to the nitriding procedure delivered comparable thicknesses of solidified case layer with normal hardness of 70–72HRC.

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