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RESEARCH ARTICLE

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ASSESSMENT OF MECHANICAL AS WELL AS METALLURGICAL PARAMETERS AIMED AT HC 71\75 THROUGHOUT ANNEALING WITHIN BELL FURNACE

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ABSTRACT

A study was made of the effect of heat treatment of high carbon steel so as to determine the mechanical and metallurgical properties before annealing as well as after annealing. Total four samples of the high carbon steel were subjected to heat treatments i.e. annealing in a bell furnace heated to a temperature of 700˚C. One from each heat treated types was prepared for micro structural and hardness studies. The hardness of the four different heat treated samples was measured by Rockwell hardness testing machine. Optical microscopy to study the microstructure and Ultimate tensile stress using respective machine. This experiment was taken to help the company that was facing a problem of decarburization of HC 71/75. In this research work we have seen that wire rod that was used for annealing got decarbonizes to a some extend and that was not acceptable for further wire drawing also for the manufacturing of spring washers. This high carbon steel wire rod after decarburization hook crack in wire drawing process as well as further manufacturing for spring washers.

Keywords: Annealing, Bell furnace, Hardness, UTS,OM,GDS.

1.0 INTRODUCTION

During the production of steel, a significant amount of work hardening takes place when the steel is rolled up into coils, for storing purpose. These steel coils are batch annealed in order to reduce the hardness and restore formability, before further production takes place as we are presuming for spring washer manufacturing. In a typical batch annealing process, several coils are annealed in a bell-shaped furnace and a reducing gas, i.e. nitrogen mixture, is passed through the coils, in a circular fashion, to remove rolling oils along with prevent oxidation. The heat is supplied from outside the inner cover by means of a heater that covers the system. Bell annealing furnace in k.d.k steel plant is used to reduce the internal strain of steel wire rod. The efficiency of bell annealing furnace applied at k.d.k steel plant the purpose to reduce the internal strain of steel wire rod was achieved by changing the cycle of operation which helps in preventing the decarburization in high carbon steel wire rod. Decarburization of high carbon steel wire rod is major problem for them because they are manufacturing spring washer with that wire rod. After decarburization Wire rod breaks during its drafting on the wire drawing machine. During the batch annealing process, heating occurs in the form of a temperature ramp, which increases to a maximum temperature of about 670°C before decreasing it to room temperature. According to experimental findings, decarbonisation usually takes place at the critical time interval shown on the temperature ramp in figure 1

1.1 Aim of Study

The purpose of this study is to show the influence of oxygen pressure on the complex segregation behaviour during the annealing of the industrial HC steel. This is done by changing the cycle of operation of bell furnace to prevent the decarburization by finding the reason of the problem as well as by comparing the result of mechanical and metallurgical parameters of HCS 71\75. To resolve the problem of decarburization in HCS 71\75 firstly we checked raw material samples before annealing and then after annealing in K.D.K Steel Plant (Unbrako).

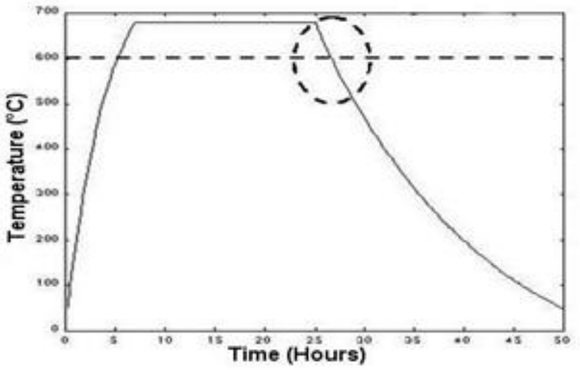


Figure 1

2 ANNEALING

Annealing is a softening process for metal that reduces internal strain caused by work hardening and facilitates recrystallization and grain growth. When metals are formed or processed, strain hardening occurs, decreasing ductility and increasing hardness. This hardening leaves metals brittle, often causing cracking or breaking during successive operations. For many applications, these residual stresses within the structural makeup of the molecules must be alleviated. Annealing returns the ductility to the metal allowing for future operations and processing.

Both ferrous (iron-based alloys such as steel and stainless steel) and non-ferrous metals (such as bronze, copper and aluminium) use this process. This raw material is cleaned to eliminate rust, scaling, dirt, and other impurities. Cleaning can be performed using acid pickling or mechanical methods, depending on the application. The metal is then placed in a furnace where it is heated to meet metallurgical requirements. Variations exist within the process depending on the type of metal being annealed and the desired outcome. It is frequently advantageous to heat the metal within a controlled atmosphere, such as nitrogen or hydrogen, to prevent chemical reactions from occurring between the metal and elements in the air. The furnace heats the metal, usually through convection and radiation, to a desired level where it is either held constant or cycled. After the heating, a controlled cooling brings the metal back to room temperature.

2.1 Bell Annealing: Bell Annealing is a type of annealing that derives its name from the shape of the furnace used during the process. Bell Annealing heats batches of metal which are placed on a base assembly, enclosed by an inner cover, and covered by the furnace. An overhead crane is used to load the base and move the equipment—when the furnace is suspended from the crane, it looks like a —bell . The base assembly is the source of convection and the main method of heat transfer to the charge. The inner cover seals in the desired atmosphere and protects the charge from the burners' direct heat. Keeping contaminants out of the annealing atmosphere prevents chemical changes as well as eliminating the formation of oxides and soot on the metal. The furnace brings the charge to the desired temperature to allow for the metallurgical changes to occur. Direct fired, tangentially fired, radiant tube, and electrical resistance are furnace types related to the method used to heat the charge. After heat treatment, cooling is performed by removing the furnace—leaving the inner cover in place to maintain the protective atmosphere. If a bright finish is desired, the metal must be cooled to near ambient temperature before exposing the metal to air. In this case, another piece of equipments utilized: a forced-cooler. The forced-cooler replaces the furnace at the end of the heating cycle and uses air and sometimes spray water to accelerate the cooling of the outside of the inner cover.

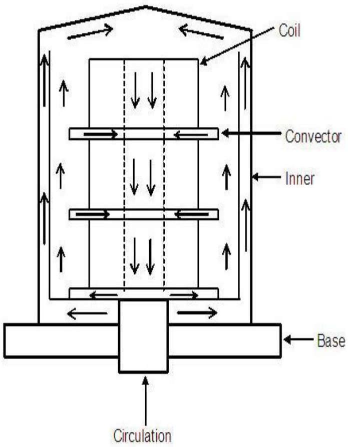
2.2 Advantages of a bell-type annealing:-

The main advantages of a Bell-Type annealing furnace are:

- Excellent temperature uniformity
- Consistent product quality
- Good production rates
- Low operating costs
- Efficient use of furnace asset by cooling with inner cover

- Savings in shop floor space requiring less capital investment and reducing material handling

Bell furnaces are used to anneal both strip and wire coils. Furnaces designed for strip are generally of a —single-stack configuration. The base diameter accommodates on coil centered over the base fan. The strip coils are stacked on top of one another, separated by convector plates. The circulated atmosphere flows up the sides and back down to the fan through the centre of the coil.



3 Methodology

Before the annealing of the wire rod there is a process that's taken is given below:

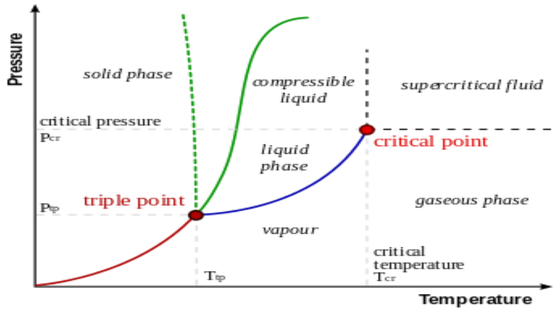
- Pickling: Pickling is a metal surface treatment used to remove impurities, such as stains, inorganic contaminants, rust or scale from ferrous metals, copper, precious metals and aluminum alloys. A solution called pickle liquor, which contains strong acids, is used to remove the surface impurities. It is commonly used to decaled or clean steel in various steelmaking processes. In picking process there are some operations that are taken are as follows:-
    - Acid Dip
    - Jet wash
    - Rinsing dip
    - Activator
    - Air pressure wash

  In 1 step the wire rod is dipped in acid tank (HCl) for removing scales and rust from the wire rod for some time then in 2 step wire rod is cleaned with jet wash for removing acid from the wire rod coil. In 3 step the coil is dipped in a tank that contains water in it for removing deposited acid then after again dipped in activator tank which is used to remove the single trace of acid from the surface of the wire rod. In 5 step the wire rod is cleaned with pressured air so that the coil of steel gets dry quickly.
- Now we came on the problem that was occurred in the annealing. There is the presence of water in the wire rod at the time of heating in the bell furnace. Company does not hold wire rod coils in open atmosphere for a long time hence, leads to presence of water as that generate oxygen as this oxygen makes the wire rod decarburized

3.1 Problem Aspects: In this problem main concern is with oxygen that is responsible for decarburization of wire rod.

1. During the heating of the wire cod in bell furnace the water that was left in coil get heated as steam generation takes place.
2. In old cycle (CYCLE 1) vacuum is given at 100ºC (Boiling Point of water)
3. In New cycle (CYCLE 2) vacuum is given at 200ºC (where nearly water gets converted into steam) as recycling with Nitrogen.
4. As the Temperature increases we know that 372ºC is the THERMODYNAMIC CRITICAL POINT OF WATER. So, there is again recycling of Nitrogen takes place at 375ºC where almost all steam goes out.
5. Again before recrystalization and recovery of grains we all over again recycled the internal gases with fresh Nitrogen stock due to the reason that recrystalization occurs at 550ºC where molecules gets a stable zone.
6. Then we goes to Soaking at 700ºC in the absence of oxygen where a material decarburization chances are more.
7. Almost similar phase for both cycles then after CYCLE 1 and CYCLE 2 depending upon the required hardness as upon its variable application for manufacturing. In our case at K.D.K STEEL INDUSTRY (UNBRAKO) we are dealing it for the manufacturing of spring washers for HC 71\75 .

3.2 Thermodynamic Critical Point of Water: In thermodynamics, a critical point (or critical state) is the end point of a phase equilibrium curve. The most prominent example is the liquid-vapor critical point, the end point of the pressure-temperature curve that designates conditions under which a liquid and its vapor can coexist. At the critical point, defined by a critical temperature Tc and a critical pressure pc, phase boundaries vanish. Other examples include the liquid–liquid critical points in mixtures.



3.2 Decarburization: Decarburization (or decarburization) is the process opposite to carburization, namely the reduction of carbon content. The term is typically used in metallurgy, describing the reduction of the content of carbon in metals (usually steel). Decarburization occurs when the metal is heated to temperatures of 700°C or above when carbon in the metal reacts with gases containing oxygen or hydrogen.

Decarburization can be either advantageous or detrimental, depending on the application for which the metal will be used. It is thus both something that can be done intentionally as a step in a manufacturing process, or something that happens as a side effect of a process (such as rolling) and must be either prevented or later reversed (such as via a carburization step).

The decarburization mechanism can be described as three distinct events: the reaction at the steel surface, the interstitial diffusion of carbon atoms and the dissolution of carbides within the steel.

The most common reactions are:-

$C + CO_2 \leftrightarrow 2\,CO$ (Carbon monoxide)

Also called as the Boudouard reaction

$C + H_2O \leftrightarrow CO + H_2$ (Carbon monoxide)

$C + 2H_2 \leftrightarrow CH_4$ (Methane)

Other reactions are that are happened are given below:-

$C + \frac{1}{2}O_2 \rightarrow CO$

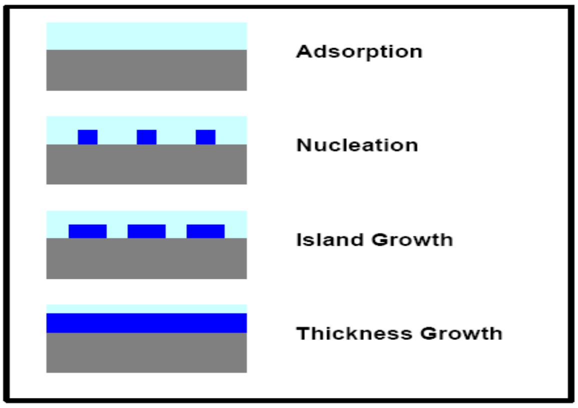
$C + O_2 \rightarrow CO_2$

$C + FeO \rightarrow CO + Fe$

High carbon steel decarb upto 250 microns in depth

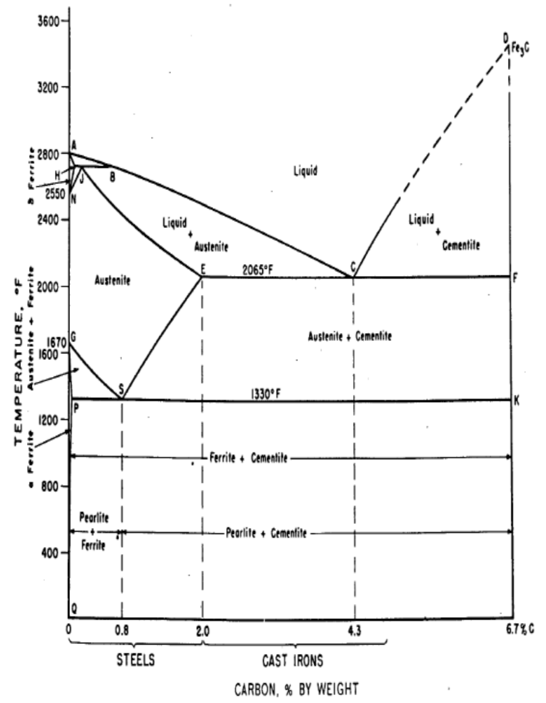
3.3 Oxidation: Oxidation can be defined as the process of combining oxygen with some other substance or a chemical change in which an atom loses electrons. In this study the focus is on the reaction between a metal and oxygen. The exposure of almost any metal to gaseous oxygen can cause the formation of an oxide. The formed oxide is not always seen as negative. The oxide constitutes a protective layer which separates the metal from the gaseous oxygen. Oxides is only one type of protective layers on metals, other include protective layers such as sulphides and halides.

Growth of Oxide Layers:



3.10 The Fe-C Phase Diagram: The basis for the understanding of the heat treatment of steels is the Fe-C phase diagram (Fig. 1).Figure 1 actually shows two diagrams; the stable iron-graphite diagram (dashed lines) and the metastable Fe-Fe3C diagram. The stable condition usually takes a very long time to develop, especially in the low-temperature and low-carbon range, and therefore the metastable diagram is of more interest. The Fe-C diagram shows which phases are to be expected at equilibrium (or metastable equilibrium) for different combinations of carbon concentration and temperature. We distinguish at the low-carbon end ferrite (α-iron), which can at most dissolve 0.028 wt.% C at 727°C and austenite (γ-iron), which can dissolve 2.11 wt.% C at 1148 °C . At the carbon-rich side we find cementite (Fe_3C) of less interest, except for highly alloyed steels, is the δ-ferrite existing at the highest temperatures [2].

Between the single-phase fields are found regions with mixtures of two phases, such as ferrite + cementite, austenite + cementite, and ferrite + austenite. At the highest temperatures, the liquid phase field can be found and below this are the two phase fields liquid + austenite, liquid + cementite, and liquid + δ-ferrite.Some important boundaries at single-phase fields include: A1, the so-called eutectoid temperature, which is the minimum temperature for austeniteA3, the lower-temperature boundary of the austenite region at low carbon contents, that is, the γ/γ + α boundary· Acm, the counterpart boundary for high carbon contents, that is, the γ/γ + Fe_3C boundary. If alloying elements are added to the iron-carbon alloy (steel), the position of the A1, A3, and Acm boundaries and the eutectoid composition are changed



he Iron Carbon Phase Diagram

4 Materials Selection: In the K.D.K Steel company (UNBRAKO) annealing of various wire rod sizes as well as grades takes place. This is fastener manufacturing company so therefore deals with variety of grades of steel. In the company I have seen lot of raw material that was being purchased from other companies and then further processes takes place on them as compared to their customers demand. In company the major problem that was occurring with a particular grade of material during the annealing i.e High Carbon Steel of 71\75 grade.It was found decarbed many a time and hence company facing problem and it need to be resolved as soon as possible. So, that's the reason of selection of that material.I have taken four samples of HCS 71\75 as their detail is given below:

Sr. no.	Size	Grade	Quantity (in Pcs.)	Remarks
1	5.50MM	HC 71\75	1	ok
2	7.00MM	HC 71\75	2	Full decarb
3	8.00MM	HC 71\75	1	ok
4	20.00MM	19MNB4M	1	ok(NOT NESSESORY)

Detail of samples of HCS that was used during annealing

4.1 Test Involved In Evaluation of Mechanical Parameters for HCS 71\75: Usually there are many test that can be used for finding the mechanical parameters of HC 71\75 but to evaluate we need only two tests and they are given below:

1. HARDNESS TEST
2. TENSILE TEST

4.2 Test involved in evaluation of metallurgical parameters for hcs 71\75: Usually there are many test that can be used for finding the metallurgical parameters of HC 71\75 but to evaluate we need only two tests and they are given below:

1. OPTICAL MICROSCOPY (OP)
2. CHEMICAL COMPOSITION ANALYSIS(GDS)
3. MACROETCH TEST

5 Material and Experimental Details

HC 71\75 steel samples are used to evaluate the mechanical as well as metallurgical parameters after annealing in bell type furnace operated electrically in the K.D.K. Steel Plant (UNBRAKO). The below mentioned table and graph are the cycle on which bell furnace is operated earlier than and that makes the wire rod partially or fully decarbed.

S. NO.	Size	Grade	Coil weight in kg	Capacity of furance in kg	Result
1	7.00MM	HC 71\75	2442	5000	PARTIALY DECARBED
2	7.00MM	HC 71\75	2458		FULLY DECARBED

5.1 Cycles That Was Used For Annealing In Bell Furnace

TABLE First cycle of annealing under bell furnace on HC 71\75

Steps	Phase	Temperature of furnace(°C)	Time Taken	Time of Operation	Vacuum Pressure (-Hg)	Remarks
1	Vacuum &	100	30 min.	15 min.	720	Nitrogen Refilling
2	Heating	175	45 min.	5 min.	600	
3		375	120 min.	3 min.	500	
4		475	60 min.	1.30 min.	400	
5	Heating	700	2 hr 30 min.	Not applicable		Decarburization phase
6	Soaking	700	4 hr 30 min.			
7	Control cooling	600	15 hr			Recrystalization
8	Atmospheric cooling	580	1 hr 30 min.			Bell out
9	Material Out	250	1 hr			Material at normal temp.

TABLE Second cycle of annealing under bell furnace on HC 71\75

Step	Phase	Temperature of furnace(°C)	Time Taken	Soaking time	Time of Operation	Vacuum Pressure (-Hg)	Remarks
1	Heating & Soaking	200	1 hr 30 min.	15 min.	xx	xx	Steam generation
2	Vacuum	200	xx	xx	15 min.	720	Nitrogen Refilling & steam out
3	Vacuum & Heating	375	1 hr 45 min.		5 min.	600	
4	Heating & Soaking	450	1 hr	30 min.	xx	xx	
5	Vacuum	450	xx	xx	1.30 min.	500	Decarburization phase & Nitrogen Refilling
6	Vacuum & Heating	475	10 min.		1 min.	450	
7	Heating	550	1 hr		30 sec.	450	
8	Heating	650	45		5 min.	450	

			min.				
9	Soaking	700	2 hr 30 min.	4 hr 30 min.	xx	xx	
10	Control cooling	600	15 hr	xx	xx	xx	Recrystalization
11	Atmospheric cooling	550	1 hr 30 min.		xx	xx	Bell out
12	Material Out	250	1 hr		xx	xx	Material at normal temp.

6 Results

6.1 Decarb Results of Annealed Material Samples: In this consequence we have found out that results that were received against the cycle 1 are decarbed and are failed but after certain changes in the cycle of bell furnace we exhausted steam and save the metal wire rod from decarburization(cycle 2) their respective results are shown in the following table given below:

S. no.	Size	Grade	Decarb (microns)		Remarks	Operation of Cycle
			Raw Material	Annealed		
1	5.50 MM	HC 71\75	7.5	10.75	Satisfactory	Cycle 2
2	7.00 MM	HC 71\75	9.836	78.06	FAILED	Cycle 1
3	8.00 MM	HC 71\75	7.377	18.57	Satisfactory	Cycle 2
4	20.00 MM	19MNB4MHC	10.13	26.7	Satisfactory	xx

Decarb results of Comparison of annealed material samples.

6.2 Results Of Hardness:

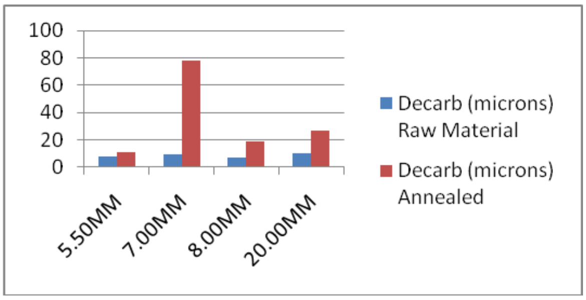
Serial no.	Size	Grade	Hardness	
			Raw Material	Annealed Material
1	5.50MM	HC 71\75	103 HRB	89 HRB
2	7.00MM	HC 71\75	105 HRB	78 HRB
3	8.00MM	HC 71\75	104 HRB	80 HRB
4	20.00MM	19MNB4MHC	112 HRB	73 HRB

Comparison of results of hardness of high carbon steel.

6.3 Results of Tensile Strength:

Serial no.	Size	Grade	UTS	
			Raw Material	Annealed
1	5.50MM	HC 71\75	891 MPa	610 MPa
2	7.00MM	HC 71\75	920 MPa	501 MPa
3	8.00MM	HC 71\75	922 MPa	502 MPa
4	20.00MM	19MNB4MHC	932 MPa	450 MPa

Comparison of results of tensile strength of high carbon steel.



7. Conclusions

From the present studies on "Mechanical and Metallurgical properties of high carbon samples" the following conclusion have been found.

1. The mechanical and Metallurgical properties of high carbon steels strongly decreases by the annealing process at 700ºC temperature.
2. The annealing process done on the bell type furnace operated electrically decreases the hardness of the high carbon steel wire rod.
3. The process done in the bell type furnace decreases the tensile strength of the high carbon steel wire rod..

4. The annealing process done on the bell type furnace operated electrically releases the stresses that are formed during casting of the high carbon steel wire rod.
5. The process done on the bell type furnace decreases strain caused by case hardening facilitates recrystallization and grain growth of the high carbon steels.
6. The annealing process returns the ductility of the wire rod as that can be used for further several operations.

As in the future scope regarding this case study certain parameters are left in this study because this study is totally depends on the problem hat was occurred in the K.D.K Plant (UNBRAKO). So, therefore case study was taken to resolve the problem only and the tests that were performed also considered relative to the various manufacturing operations such as for further drawing, coiling in coiling machine and for spring washer .This problem causes short length in coiling machine as lack of production hence that scenario can also be elaborated but taken for further scope.

8. Acknowledgement

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