EFFECT OF INDUCTION HARDENING ON HIGH CARBON STEEL FORGINGS

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Abstract— **Steel is an alloy of iron and carbon. Forging of steel imparts some better strength and impact load characteristics in a component. By varying the amount of carbon in steel, its quality can also be controlled easily. Thus for better property yielding, heat treatment processes are adopted. Case hardening is a common heat treatment process of forming harder case, and for which induction hardening technique is used widely. This causes the metal to harden in the selected areas without affecting the properties of the part as a whole.**

As per availability, the high carbon steel of 0.73% carbon content is selected as the specimen, which is further forged by upsetting method. Now to remove the surface irregularities, formed during forging, the specimen is machined in a lathe. But prior to that, annealing process is adopted to increase its machinability.

In the induction heater, the specimen is pre-heated first, and then heated and quenched by water spray to form a hard case. Then the hardness and micro-structures are evaluated and compared at various levels of operations.

The result shows that the value of hardness is same before forging and after annealing, but increases somewhat after forging. The hardness value increases massively at the case after induction hardening and reduces gradually to core.

Micro-structural observation reveals that the dendritic structures are broken into fine particles during forging and the annealing causes coarsening of fine ferrite and pearlite particles. But the induction hardening yields a semi-martensitic structure at the case to a soft core at the center.

Index Terms—**Case Hardening, Forging, High Carbon Steel, Induction Hardening.**

I. INTRODUCTION

Steel is an alloy that consists mostly of iron and 0.2 - 2.1% carbon by weight [1]. And carbon is the most common alloying element for iron, which act as a hardening agent. By varying the amount of carbon and its form of presence in steel (solute elements, precipitated phase), the qualities such as the hardness, ductility, and tensile strength of the resulting steel can be controlled.

In carbon steel, the main interstitial alloying element is carbon. On the basis of which, it classified as mild and low carbon steel, medium carbon steel, high carbon steel and ultra-high carbon steel. Steel content approximately 0.6–0.99% carbon is called high carbon steel, which is very strong. As the carbon content in steel increases, it becomes harder and stronger with the sacrifice of its ductility. Thus heat treatment operation is adopted.

Forging is basically a manufacturing process, involving the shaping of metal using localized compressive forces. Thus it can produce a part that is stronger than an equivalent cast or machined part. As the metal is shaped during the forging process, its internal grain deforms to follow the general shape of the part, results the fiber structure throughout its mass, giving rise to a piece with improved strength and impact load characteristics. Forging is often classified according to the temperature at which it is performed, i.e. cold, warm, and hot forging. However the iron and steels are generally hot forged [1]-[4].

Heat treatment is an industrial process, used to alter the physical, sometimes chemical, and mostly metallurgical properties of a material. Heat treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve a desired result such as hardening or softening of a material. The most commonly used heat treatment techniques include annealing, normalizing, hardening, tempering, case hardening, precipitation strengthening, etc. So heat treatment only applies to processes where the heating and cooling are done for the specific purpose of altering properties intentionally [1].

Case hardening or surface hardening is the process of hardening the surface of a metal by infusing elements into the material's surface, forming a thin layer of a harder alloy. It is usually done after forming the parts to its final shape. It is generally specified by the hardness and its case depth. The case depth can be specified in two ways: total case depth or effective case depth. The total case depth is the true depth of the case. The effective case depth is the depth of the case that has a hardness equivalent of HRC50. The commonly used case hardening processes includes flame hardening, induction hardening, carburizing, cyaniding, nitriding, carbonitriding etc. [1]-[6]-[7].

Induction hardening is a form of heat treatment in which a metal part is heated by induction heating and then quenched. Thus the quenched metal undergoes a martensitic transformation, increasing the hardness and brittleness of the part. Induction hardening is used to selectively harden areas of a part or assembly without affecting the properties of the part as a whole [3]-[5].

II. MATERIAL AND METHOD

In this present study the high carbon steel of 0.73% carbon content with 25mm diameter and 170 mm length was chosen as per availability.

This specimen is then passes through the forging operation, i.e. the upsetting process. Now as the forgeability of high carbon steel is less, thus percentage reduction is restricted

Manuscript received June 10, 2011.

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upto 30 % only, because the specimen buckled severely beyond this. Prior to that, a small piece of sample is collected for hardness testing and microstructure observation. The upsetting process was chosen purposely to minimize the air gap between the job and inductor coil during induction heating.

The sample is heated in the blacksmith's hearth to the forging temperature of the 0.73% carbon steel, i.e. 1100^0 and length is reduced partially by upsetting in a one tonne pneumatic hammer, till it starts buckling and loses its forging temperature. Forging operation is continued after reheating till the diameter of the sample become 30 mm with 50 mm reduction in length. A small piece of sample is sheared of for hardness testing and micro-structural observation after proper preparation [4].

After forging the outer surface of the sample is irregular in shape as open die forging method is adopted, but the induction coil is circular in shape. So to shape the sample circular in cross section, machining, i.e. turning in lathe is necessary. But the machinability of high carbon steel after forging is very poor. So to suit the machinability and to make the structure suitable for induction hardening, annealing is adopted.

Theoretically the annealing temperature of the 0.73% carbon steel is 880^0 C, but to overcome the heat losses, annealing is conducted in a resistance furnace at 900^0 C temperature. The soaking time provided is 1 hr/inch cross section of the specimen. As the diameter of the sample is more than 1 inch (i.e. 30 mm), so soaking time is 90 min in present case, after which furnace cooling is adopted till the temperature reach to the room temperature. After the annealing operation, a small piece from the sample is sheared-off for hardness checking and micro structural evaluation, as previous. Then the remaining specimen was machined to circular cross section on a machine lathe. After which its diameter reduced to 25 mm.

The induction heating is basically a process of heating an electrically conducting object, usually metal, by electro magnetic induction. Here eddy current are generated within the material and the electrical resistance within the metal leads to Joule heating. Though an induction heater is always an electromagnet, thus heat may also be generated by magnetic hysteresis losses within the material [3].

For induction hardening, high frequency (400 KHz), 15 KW power rating induction-heater, with induction coil of 78 mm internal diameter and 55 mm height, is utilized. The machine was switched-on after rotating the job slowly for uniform heating. And it is pre-heated first by moving it down and up through the induction coil. This releases some amount of internal stresses, developed during machining and make the specimen suitable for further heat treatment. Finally the job is feed slowly through the induction heater. Due to eddy current, the surface of the specimen get heated up (which can be observed by optical pyrometer) and as it reaches to 920^0C, it again fed into the downward direction where a spray of water quench it to room temperature. Again a small piece of specimen is sheared off for hardness and micro-structural evaluation [5].

The optical pyrometer used here is a non-contact type of instrument, used to measure thermal radiation and there by determine the temperature of a red hot surface of an object [1].

Before and after forging, after annealing and after induction hardening, the specimen collected for hardness testing is polished in tool room grinder and after that various grade of emery paper, i.e. from coarse to finer, and then the various zone is evaluated by Rockwell hardness tester.

The Rockwell hardness tester basically determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload and there are different scales denoted this hardness and indicated by a single letter. Hence in the present study C scale is utilized to denote the Rockwell hardness number [2].

Similar as hardness testing, the various sample also collected for micro-structural evaluation. For this the specimen are polished first on the polishing machine with emery paper of grade 320, 400 and 600, etc. till a smooth surface of without scratch is obtained. Then the sample was polished in the cloth polishing machine till the surface has turned into mirror impression. After that the sample was etched by 2% Nital etchant (solution of 2% concentrated nitric acid in absolute methyl alchohol). The etchant reacted differently with the different phases like ferrite and cementite, so that they could be readily distinguished under the microscope. Grain boundaries were attacked more easily and at a faster rate by the etchant. After etching, the sample was washed in running water and then dried in the air. Then the sample examined under the metallurgical microscope. Where the microscope is an instrument used to see an object that is too small for the naked eye and the metallurgical microscope can make it possible to take those pictures in a zooming form.

III. RESULTS

The result shows that the value of hardness of the parent material, i.e. before forging, is 32 Rc. But it rises to 34 Rc throughout its cross section after forging. The value of Rockwell hardness in C-scale after annealing is again becomes 32 throughout its mass. And after induction hardening the hardness obtained at the surface is 57 Rc, which is gradually becomes to 32 Rc at the core. The hardness at various steps of operation is depicted in the table 1, and the hardness value after case hardening at different cross section is depicted in table 2, and represented by graph in Fig. 1.

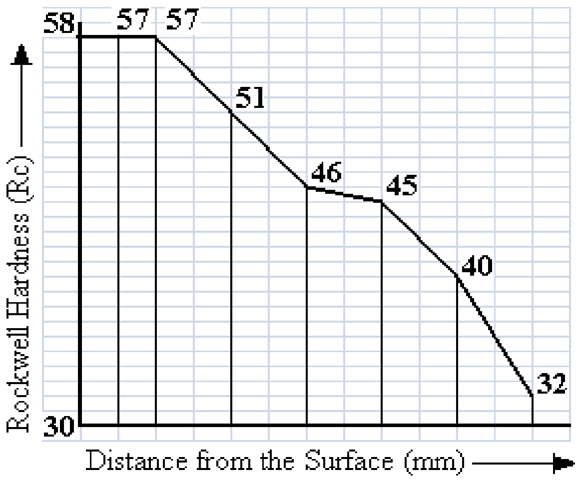

Figure 1: Rockwell hardness values from the surface in C-scale.

Table 1: Hardness value at various stages of operation

Hardness Evaluation	Rockwell Hardness in C-Scale (Rc)
Before Forging	32
After Forging	34
After Annealing	32
After Case Hardening	57(case)
	32(core)

Table 2: Hardness value at various cross sections after induction hardening.

Distance from the Surface (mm)	Rockwell Hardness in C-Scale (Rc)
1	57
2	57
4	51
6	46
8	45
10	40
12	32

By micro-structural observation, it was found that the sample had a dendritic structure before forging. After forging these dendritic structures are broken into fine grained structures. The coarse ferrite and pearlite grains are observed after annealing in micro-structural observation. The induction hardening yields approximately 50% martensite at the

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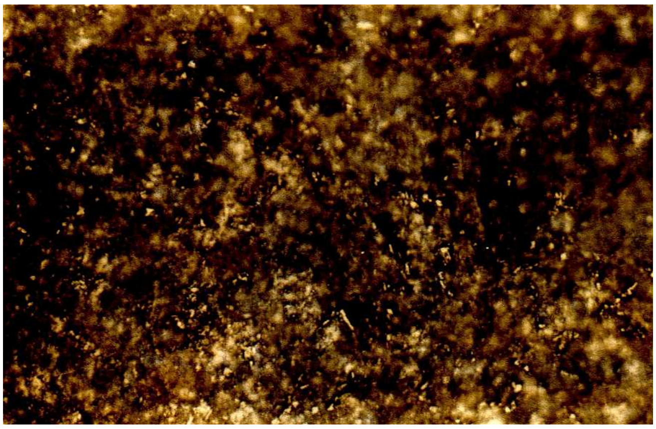

Figure 2: Micro-structure after Forging, Etched, 500

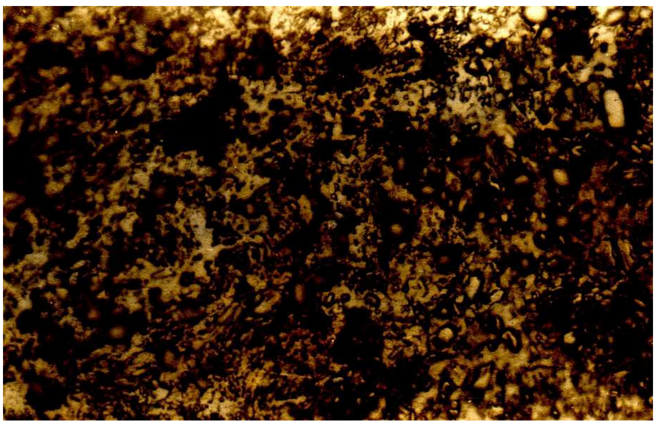

Figure 3: Micro-structure after Annealing, Etched, 500X.

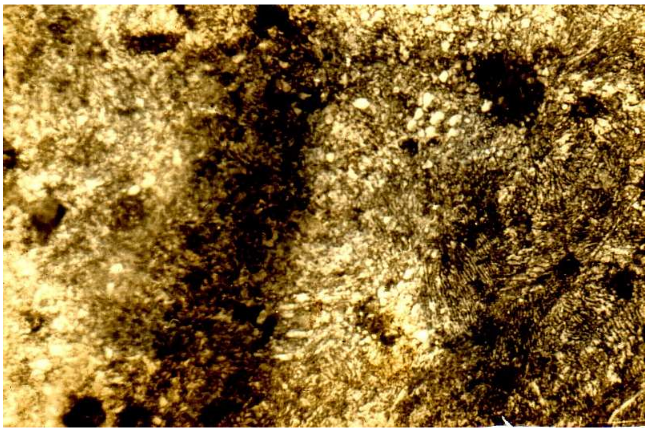

Figure 4: Micro-structure after Hardening, Etched, 500X

surface, but at the sub-surface layer region, the availability of martensite is very less. In the remaining space, the ferrite and pearlite are only observed. The micro-structures at various steps of operation are represented by its photographs in Fig. 2, 3 and 4.

IV. DISCUSSIONS

In the present study, the sample selected is basically high carbon steel of carbon content 0.73%. The result revealed that hardness value of parent metal before forging is Rc 32, and it is quite obvious, as the supplier opined that to supply hot rolled process annealed high carbon steel. This is also supported by presence of coarse ferrite and pearlite in micro-structure.

Forging causes the dendritic structure of parent metal to brake down into fine grains, and elongate in the perpendicular direction of applied forces. To observe elongated grain flow direction [1], macro-structural observation is required, which is out of area of interest of the present study. The fine grained ferrite and pearlite are observed in the micro-structural observation as shown in figure 2 with 500 magnifications. And as the forging increases the strength and toughness of ductile metal, thus the hardness value get increases to Rc 34 after forging.

As the annealing causes refinement of grain structure as well as grain growth, thus coarse ferrite and pearlite are viewed (Fig. 3) in micro-structural observation of annealed sample. The hardness value, i.e. Rc 32, also decreases due to this.

The induction hardening yields approximately 50% martensite at the surface of the specimen, due to that, the hardness value at the surface is Rc 57. Now, as the availability of martensite at the sub-surface layer is very less, so the hardness value decreases gradually, and becomes Rc 32 at the core, which is basically an annealed structure of ferrite and pearlite.

In the present study the value of hardness obtained is only 57 Rc with a case depth of 2mm. This is only because of approximately 50 % martensite formation on the surface of the specimen and use of high frequency equipment respectively.

To achieve more hardness at the surface, i.e. approximately 100% martensite, the job diameter should be increased, so that the air gap maintained between the job and coil should be as minimum as recommended, which subsequently helps to achieve the proper hardening temperature. It is one of the major drawbacks of the induction hardening, i.e. one coil is only suitable for very number of components.

Another thing is more important to achieve more hardness at the surface, i.e. drastic quenching. After achieving proper hardening temperature, if high and uniform rate of water is sprayed on the job, then the probability of martensite formation will be quite high.

To increase the case depth, low frequency equipment is recommended, as high frequency equipments are only suitable for case depth of very few mm. By increasing the heating time, i.e. time to penetrate the heat towards core, the case depth can also be increased.

V. CONCLUSION

Generally steel having approximately 0.6–0.99% carbon content is known as high carbon steel. It is very much though, strong and hard. It is mainly used for springs, high-strength wires, and as a cutting tool. Now if the carbon percentage in steel is increased, then the hardness values of it also increase with subsequent decrease of its ductility, i.e. increase of its brittleness. So to maintain the ductility within some reasonable limit, case hardening is recommended. Induction hardening is one of the most clean, fast and popular method of case hardening. Now if the high carbon steel is forged, its toughness, strength and impact resistance will increases across its flow lines. Then if it is recommended for case hardening, its outer surface will be more harder (i.e. imparting more wear resistance) with reasonable level of ductile, strong and tough core, which is more suitable as a cutting tool and for other applications.

In the present study, the high carbon steel having coarse ferritic and pearlitic structure is selected as a sample. Forging imparts toughness in it with the brake down of its grains into fine particles. As the annealing causes refinement of grain structures, thus yield coarse ferrite and pearlite again. Induction hardening yields semi-martensitic surface layer with high hardness, and ductile-tough core and sub-surface. Thus a case with hardness 57 Rc is the ultimate result.

For achieving higher hardness, minimum air gap between job and coil, and subsequent super cooling is required. As the fine grained particles react more easily in induction hardening, thus larger reduction during forging is preferable. For higher case depth, low frequency equipment with prolong heating is suitable.

So in conclusion, it is essential to mention that the electromagnetic induction is a method of heating of electrically conductive materials, as during heat treatment of metals. It is quick, easy, quite, safe, clean, time saving, material saving, energy saving method of heating process yield higher production rates. It is largely applied in transportation field (such as case hardening of crank shaft, cam shaft), machine tool field (such as surface hardening of lathe bed) and metal working field (such as induction hardening rolls of rolling mill) etc [6]-[7]. Hence in near future, the induction hardening is going to be the most superior heat treatment process rather than the others [5].

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