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Effect of Heat Treatment on Surface Hardness of Dth Hammer - A Case Study

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Abstract: This case study examines the effect of heat treatment on the surface hardness of a Down-The-Hole (DTH) hammer. The study involved subjecting the hammer to various heat treatment processes, including carburizing, quenching, and tempering followed by hardness testing to determine the resulting changes in surface hardness. The results of thestudy suggest that heat treatment significantly impacts the surface hardness of the DTH hammer, with quenching and tempering resulting in the highest surface hardness values (55-60 HRC). The study provides valuable insights into the optimal heat treatment processes for enhancing the surface hardness of DTH hammers, which could have important implications for the mining industry. Heat treatment is a critical process in the manufacturing of DTH (Down-The-Hole) hammers, as it improves the surface hardness of the hammer body and bits from 30-35 HRC to 55-60 HRC. The process involves heating the hammer components to a specific temperature and then cooling it at a controlled rate. This alters the hardness of the material. The type of heat treatment process depends on the type of material used and the desired properties. Common heat treatment methods used for DTH hammers include quenching and tempering, hardening, and tempering, and surface hardening. The end goal of heat treatment is to produce a DTH hammer that can withstand high impact loads, abrasion, and corrosion, ensuring high performance and longevity in drilling applications.

Keywords*: Down-The-Hole (DTH) hammer, Surface hardening, Abrasion.*

1. Introduction to DTH hammer

The DTH drilling method is growing in popularity, with increases in all applicationsegments, including blast-hole, water well, foundation, oil & gas, cooling systems anddrilling for heat exchange pumps. Applications were later found for the DTH method underground, where the direction of drilling is generally upwards instead of downwards. Different types of Hammers depending on the type of soil and the working conditions areproduced. The different types of hammers are valve and valve less types. The way to choose suitable drilling equipment is complicated and a lot of information is required to reach performance and economy in the operation.

The DTH Hammer is a Pneumatic vibrator which impacts the additional downwards force rather than the rotary motion on to the multi point cutting tool that cut the rocks and soil used to make holes or bores. We are Designing and fabricating the DTHHammer, the present system of manufacturing DTH Hammer is consuming around 35kgsof material and we are trying to reduce the material consumption by decreasing rough turning, it leads to availability of DTH Hammer at lower cost and profits for the management. We are Doing our project at KGR industries cherlapally.

The impact energy different types of hammers depend upon the type of soil and the working conditions. The different types of bits are valve and non-valve type. The way to choose suitable drilling equipment is complicated and a lot of information is required to reach performance and economy in the operation. Aspects that must be taken into consideration are the purpose of the borehole, geology, hydro-geology pump, method of drilling.

Sample image of DTH hammer and its parts.

Material used for DTH Hammer is EN36C is a case hardening steel or nickel chromium steel. It is low carbon steel or carburizing steel that offers high core strength, high fatigue strength, high temperature resistance and high harden ability. It can achieve carburized case hardness of 60-65 HRC, but provides ultrahigh core properties for demanding shaft and gear applications. It is high tempering temperature (900°C) offers increase in thermal stability relative to conventional gear steels.

The objectives of this paper is to study the various heat treatment processes, selection of appropriate heat treatment processes for specific materials and to investigate the effect of heat treatment on surface hardness of the material.

Future scope of this research is sustainability of material to withstand various earth conditions during mining and boreholes is becoming costly with existing base materials. The surface hardness required for withstand mining and boreholes is around HRC 40-60, which costs around Rs. 1050.00per kg. It leads heavy maintenance cost for mining and borewell industries. To reduce the cost of DTH hammer further by changing the base material, various heat treatment processes and improving the productivity through work study and time study techniques to achieve the same properties of DTH hammer for the same application.

2. Material selection and its properties of DTH hammer

The main force which acts on the DTH hammer is the shock wave which isproduced by the piston due to Collison with the Drill bit. It has to with stand High working air pressure up to 20 bars. Piston requires high core strength, excellent toughness, and fatigue resistance and all other parts require good ductility and shock resisting properties. To fulfil these requirements, they selected EN 36C grade steel alloy for piston and drill bits and EN19C grade steel alloy for Hammer case, Control tube, Control tube head, Top sub, Top valve, and Coupler.

Material Composition of EN 36C (weight %)

Table: Material composition of EN36C

	C	Mn	Si	Cr	Ni	Mo	S	P
Min	0.12	0.30	0.10	0.60	3.00	0.10		
Max	0.18	0.60	0.35	1.10	3.75	0.25	0.05	0.05

Properties of EN 36C

EN36C steel is low carbon; nickel chromium case hardened steel generally used in thedynamic environment due to its Corrosion resistance, High strength, Shock resistance, good fracture toughness properties.

Material Composition of EN 19C (weight %)

Table: Material composition of EN 19C

	C	Mn	Si	Cr	Mo	S	P
Min	0.35	0.50	0.15	0.90	0.20		
Max	0.45	0.80	0.30	1.50	0.40	0.040	0.035

Properties of EN 19C

EN19 Steel is a high Carbon Quenched and Tempered Alloy Structural steel, itbelongs to the high-quality medium carbon, Oil Quenched & Tempered Hardened.

Thermal properties

Table: Thermal properties of EN19C

Process	Working Temperature (ºC)
Forging	1050 to 850
Annealing	680 to 720
Normalizing	840 to 880
Quenching	830 to 860 (oil)
Tempering	520 to 560

Forging parameters

Generally employed forging method is Closed Die Forging which is driven by belt drives. The Forging dead weight used is 2 Tones. Furnace used is Induction type and its Max capacity is 400KWThe Temperature they prefer for forging is 1000°C – 1050°C. The melting point for EN36C and EN19 is 1425^{0}C.

Heat treatment involves the use of heating or chilling, normally at extreme temperatures, to achieve the desired result such as hardening or softening of a material. Heat treatment techniques include annealing, case hardening, precipitation strengthening,tempering, carburizing, normalizing, and quenching.

In Gas Carburizing Method, Methanol (37.4% of C) and Acetone (62% of C) is used.

In Sealed Quenching Method, Methanol (37.4% of C) and Liquefied Petroleum Gas (80.714% of C) is used.

In Sealed Quenching they follow Boost Diffusion cycles which means Once a highconcentration of carbon has developed on the surface, during what is commonly called the"boost stage", the process normally introduces a "diffuse stage" where solid state diffusion occurs over time. This step results in a change in the carbon concentration, or carbon gradient between the carbon rich surface and the interior core of the metal. The result is a reduction of the carbon concentration at the surface while increasing the depth of carbon absorption.

KGR industries performs Gas Carburizing, Sealed Quenching to increase the carbon percentage from 0.75 % – 0.90% depending upon the application and requirement.and also obtain a case depth up to 2.2 - 2.4mm.

Gas carburizing furnace

Gas carburizing furnace is a surface hardening process used to increase the hardnessand wear resistance of steel components. The process involves exposing the steel to a high carbon atmosphere at elevated temperatures, typically between 850°C and 950°C, for an extended period.

During the carburizing process, carbon atoms diffuse into the surface of the steel and create a high-carbon concentration layer, which is typically between 0.5 mm and 2.5 mm thick, depending on the process parameters and the desired case depth. This layer of high-carbon steel is then hardened by quenching in an appropriate medium, such as oil or water.

Gas carburizing furnace

Overall, gas carburizing furnace is a well-established process for producing high- quality, wear-resistant steel components. However, it is important to note that the processcan also result in distortion or cracking of the parts if not carefully controlled, and post- carburizing heat treatment and finishing operations may also be required to achieve the desired final properties.

Sealed quench furnace

A sealed quench furnace heat treatment process can be used for the heat treatment of a DTH hammer. The process involves several steps, including Pre heating, Carburizing, Quenching, Tempering.

Sealed quench furnace

Overall, the sealed quench furnace heat treatment process is an effective way to improve the performance and durability of a DTH hammer. By carefully controlling the process parameters, such as temperature, time, and quenching medium, it is possible to achieve the desired combination of hardness, toughness, and wear resistance properties.

3. Heat treatment process

After machining all parts are come for Heat treatment, these are considered as theraw materials for the Heat treatment.

Machined parts for heat treatment

Carburizing

Carburization of EN36C steel, involves following steps:

Preheat the steel to a temperature of around 850°C to 900°C.

Place the steel in a carburizing furnace or a sealed container with a carbon-rich atmosphere, such as a gas mixture of carbon monoxide and hydrogen.

Heat the steel to a temperature of around 930°C to 950°C for a period of several hours to allow carbon to diffuse into the surface layer.

Quench the steel in oil or water to harden the surface layer.

Temper the steel by heating it to a temperature of around 150°C to 200°C for several hours to reduce the brittleness of the hardened surface layer. The carburizing process can be adjusted by varying the time and temperature parameters to achieve the desired surface hardness and case depth. It is important to carefully control the process parameters to avoid excessive distortion or cracking of the steel. While heating process is going on to diffuse the Carbon into the metal for Gas carburizing process we are using Carbon rich gases are Acetone (62.0% of C) and Methanol(37.4% of C), at 750^0C we are supplying the Methanol and at 830^0C - 850^0C we can supplythe Acetone.In Sealed quench furnace at 750^0C we can supply the methanol and at 830 - 850^0Cwe can supply the LPG (80.714% of C) and also obtain carbon at case depth up to 2.2 - 2.4mm.

Gas carburizing and sealed quench furnace

Annealing

The Quenching temperature for EN36C material is 820ºC. The quenching hardness can beachieved from 60-65 HRC.

For EN19C material is 860ºC. The quenching hardness can be achieved from 48-55 HRC. The materials are Heated and quenching into the MF (medium fast) high quench oil.

Quenching external cylinder

Tempering

Tempering is commonly used in the production of steel, where it is often used to reduce the brittleness and improve the toughness of hardened steel. It is also used in the production of other metals and alloys, including copper, aluminum and titanium. The tempering can be done at 520-560ºC for the EN19C material, 40-42HRC and for the EN36C material tempering can be done at 180ºC, HRC 55-58 is for Pistons, Guide bush and Chucks; for external cylinder 39-40HRC can be achieved.

For tempering hardness for EN 36C bits the core hardness and case hardness can be different. The core hardness can be 38-43 HRC and shank hardness can be 55-58HRC. The temperature they most preferred is 800°c-920°c to get prescribed Carbon percentage and Case depth.

Results and Discussion

Piston after heat treatment

It is made up of EN36C material, base hardness of the EN36C material is the 36.4 HRC. The heat treatment processes for piston are;

Before heat treatment piston:

	HRC	Carbon %
EN36C	36.4	0.12 - 0.18

After heat treatment piston:

Process	HRC	Carbon %
Carburizing	-	0.75/ - 0.90
Hardening	60 – 65	-
Tempering	55 – 58	-

After heat treatment process the piston is one of the most critical parts of the hammer, and it is responsible for generating the high-frequency percussive force that breaks up the rock formation. Heat treatment can significantly improve the piston's wear resistance, strength, and durability, making it more resistant to damage and wear during the drilling process.

Result of drill bit

DTH drill bit after heat treatment

It is made up of EN36C material, base hardness of the EN36C material is the 36.4 HRC. The heat treatment processes for drill bit are;

Before heat treatment of drill bit:

	HRC	Carbon %
EN36C	36.4	0.12 - 0.18

After heat treatment of drill bit:

Process	HRC	Carbon %
Carburizing	-	0.75 - 0.90
Hardening	60 – 65	-
Tempering	Shank hardness (55 - 58)	-
	Core hardness (38 - 43)	-

The bit is the part of the hammer that directly contacts the rock formation, and it isresponsible for breaking up the rock into smaller pieces. Heat treatment can significantly improve the bit's wear resistance, strength, and durability, making it more resistant to damage and wear during the drilling process.

Case depth result for EN36C

In EN36 material; the carbon percentage can be doped up to 2.2 - 2.4mm. This casedepth can be checked by the etchant called “Methanol Nitric acid” which contains methanol(98% in ml) and nitric acid (2% in ml).

Sample piece of EN36C material

In the above picture we can find the sample piece of EN36C material and surrounded by dark black circle which denotes how much carbon can be doped into the material and carbon case depth can be verified by the etchant called “Methanol Nitric acid”which contains methanol (98% in ml) and nitric acid (2% in ml).

Case depth testing for drill bit

Before heat treatment chucks:

	HRC	Carbon %
EN19	28 – 34	0.35 - 0.45

After heat treatment chucks:

Process	HRC	Carbon %
Hardening	48 – 55	Same as previous
Tempering	38 – 42	Same as previous

Chucks after heat treatment

The DTH hammer top sub is a critical component of the drilling process, and it is responsible for connecting the hammer to the drill string, transmitting the percussive force to the drill string, ensuring a smooth drilling operation, reducing wear and tear on the drill string, and providing stability to the drilling process. It must be carefully designed to optimize the drilling operation and ensure maximum efficiency and reliability.

Before heat treatment of External cylinder:

	HRC	Carbon %
EN19	28 – 34	0.35 - 0.45

After heat treatment of External cylinder:

Process	HRC	Carbon %
Hardening	48 – 55	Same as previous
Tempering	38 – 42	Same as previous

External cylinder before and after heat treatment

The external cylinder is responsible for containing the compressed air or other fluids that drive the hammer's piston. The high-pressure air or fluid is stored in the cylinder and is released through the hammer's internal components, generating a high- frequency percussive force. It also protects the hammer's internal components from damage. It must be made of high-strength steel or other durable materials, which can withstand the high-pressure air or fluid and protect the internal components from wear and tear. It helps to control the drilling speed by regulating the amount of compressed air or fluid that is released through the hammer. By adjusting the flow rate of the compressed air or fluid, the drilling speed can be controlled, which is important for optimizing the drilling operation. It is designed to dissipate heat generated during the drilling process. The high- frequency percussive force generated by the hammer can cause the hammer to heat up, and the external cylinder must be designed to dissipate the heat and prevent damage tothe hammer.

Before heat treatment Guide bush:

	HRC	**Carbon %**
EN19	28 – 34	0.35 - 0.45

After heat treatment Guide bush:

Process	**HRC**	**Carbon %**
Hardening	48 – 55	Same as previous
Tempering	38 – 42	Same as previous

The guide bush is an essential component of a DTH hammer that helps guide the drill bit during the drilling operation. The guide bush is typically made of high-quality steeland is designed to fit tightly into the hammer's chuck or bit holder.

During the drilling operation, the guide bush ensures that the drill bit remains centeredin the hammer and aligned with the drilling axis. This alignment is critical for ensuringthat the drill bit drills straight holes, minimizing the risk of deviation or deflection.

The guide bush also helps to protect the internal components of the hammer from wearand damage caused by the drill bit's rotation and percussive force. By providing a stable and durable guide for the drill bit, the guide bush can extend the lifespan of thehammer and reduce maintenance costs.

Overall, the guide bush is a critical component of a DTH hammer that helps ensure efficient and accurate drilling operations while also protecting the hammer's internal components from wear and damage.

4. Conclusion

The heat treatment process of a DTH hammer involves heating and cooling the steel material to alter its properties, such as increasing its hardness and strength. The specific heat treatment process used can vary depending on the type of DTH hammer andthe desired properties.

The heat treatment process involves several stages, including Carburising, annealing, Skinning, Hardening, and tempering. During annealing, the steel is heated to a high temperature and then slowly cooled to improve its ductility and toughness. Quenching involves rapidly cooling the steel material to increase its hardness and strength, while tempering involves reheating the material to a specific temperature to reduce its brittleness.

Overall, the heat treatment process of a DTH hammer is crucial to ensure its durabilityand performance during drilling operations. Proper heat treatment can increase the lifespan of the hammer and improve its efficiency in drilling through rock formations.

By these processes we can improve the hardness of EN 19 material by 135% and for EN36C material hardness will be improved after all heat treatment processes by 118% for drill bit shank and for internal components improved by 159% hardness.

Refrences

[1] http://www.kgrindustries.co.in/

[2] Effects of Working Angle on Pneumatic Down-The-hole Hammer Drilling by Zhi Zhao, YingfengMeng, Yongjie Li, Xiangchao Shi and Chengliao Xiang. Rock Mech Rock Eng (2015) 48:2141–2155. DOI 10.1007/s00603-014-0667-9.

[3] Numerical simulation of impact on pneumatic DTH hammer percussive drilling Article in Journal of Earth Science · October 2009 DOI: 10.1007/s12583-009-0073-5 by Bu Changgen, Qu Yegao, Cheng Zhiqiang and Liu Baolin.

[4] Design and Analysis of Down the Hole Hammer Using Creo 3.0 By P Vamsi.

[5] Krishna, V. Baleshwar Rao, D.V. Srikanth. ISSN: 2278 – 7798 International Journalof Science, Engineering and Technology Research (IJSETR) Volume 5, Issue 10, October2016.

[6] Krishna, V. Baleshwar Rao, D.V. Srikanth. ISSN: 2278 – 7798 International Journalof Science, Engineering and Technology Research (IJSETR) Volume 5, Issue 10, October2016.

[7] New trends in manufacturing process of Down-To-Hole Button Bit by Koteswara rao. B, D. Mohan krishnudu, D. Muralidhar Yadav. International Journal of Science, Engineering and Technology Research (IJSETR), Volume 4, Issue 2, February 2015.

[8] Down-The-Hole Hammer Drilling System Driven by a Tubular Reciprocating Translational Motion Permanent Magnet Synchronous Motor by Shujun Zhang, Lars Norum, Robert Nilssen and Robert D. Lorenz. Department of Electric Power Engineering, Norwegian University of Science and Technology, Norway Department of Mechanical Engineering, University of Wisconsin-Madison, USA.