INVESTIGATION OF THE HARDNESS AND STRUCTURE OF BUCKET TEETH FOR HYDRAULIC EXCAVATOR WITH THE VARIOUS HEAT TREATMENT PROCESSES

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Abstract: To manufacture the bucket teeth with optimum properties for hydraulic excavator in Mandalay industrials at Myanmar is the objective of this research paper. In the manufacturing process has the number of steps to produce the quality bucket teeth. The main processes of this paper are casting, heat treatment, hardness testing and microscopic examination. In this paper used the medium carbon steel with the composition Fe=96.1%, C=0.6%, Cu=0.05%, Mn=0.762, P=0.112, Cr=1.424%, S=0.04% and Si=0.966% for the bucket teeth. After casting, select and prepare the test specimens for heat treatment, hardness test and microscopic examination. In the heat treatment process, heating in the muffle furnace with the temperature 850˚C and 900˚C, quenching in the four quench media (air, water, salt water and oil) and tempering with the temperature 200˚C, 300˚C, 400˚C, 500˚C. In this research, the highest hardness number is 39 HRC and the second highest hardness number is 35HRC. From the microscopic examination the specimen no. 6 has the martensite structure with the high hardness and brittleness properties and specimen no.7 has the sorbite structure with the medium hardness and high toughness properties by metallurgical handbook. Finally, the specimen no.7 result is more suitable for the bucket teeth and it has the optimum properties.

Keywords: bucket teeth: medium carbon steel: microstructure: hardness: heat treatment

1. INTRODUCTION

Hydraulic excavator used in construction, mining, forestry, cleaning, digging and carry. Bucket teeth are located at the tip of the bucket, so that they are easily damaged by the direct contact with the media. Various types of ground engaging tools (teeth) are general duty, extra duty, penetration, penetration plus, heavy penetration, heavy abrasion, wide, spike, and double spike.

Bucket teeth are the wear replacement parts of excavator. Such bucket teeth will be assembled by a pin, retainer and lock. Then teeth are fitted to excavator bucket. For its special working condition in soft soil and rock environment, there is a high demand of wear resistance and high hardness, thus to longer the working life.

Bucket teeth are made by lost foam casting process to obtain the optimal properties. Main manufacturing process for excavator bucket teeth includes: tooling, foam manufacturing, plaster shell making, assembly, melting, analysis the composition, casting, heat treatment, analysis properties and microstructures and painting.

To investigate the microstructure and properties of the bucket teeth for the hydraulic excavator, we much think a lot of factor and need the testing instruments.

2. THEORETICAL BACKGROUND

The three main research areas are heat treatment, hardness test and microscopic examination of the bucket teeth materials.

2.1. Heat treatment

Heat treatment is the combination between heating process and controlled cooling, aimed to obtain the expected material properties. Heat treatment has the four sample process. Process annealing, annealing, normalizing, and spheroidizing are commonly used for steels. These heat treatment are used to accomplish one of three purpose (1) eliminating the effect of hot work ,(2) controlling dispersion strengthening or(3) improving machinability.

2.2. Hardness Test

Hardness test experiments are efficient way of measuring hardness of an engineering material. Hardness is a measure of a material's resistance to localized plastic deformation. Hardness of a material describes how hard it is to deform that particular material. Quantitative hardness techniques involve a small indenter, where the indenter is forced on to a surface of a material to be tested. The force and the rate of load are widely and frequently used are: they are simple and inexpensive, the test is non-destructive and the process is very quick. The hardness data is very helpful information for any engineering material. This data can be used to estimate the different mechanical properties.

2.3. Microscopic Examination

Microscopic examinations could satisfy many purposes and one of the key persistence of it in materials engineering is examining defects in materials. Defects in a material are determines important properties and performing microstructure examinations helps to develop relations between the microstructure of the material and its properties.

The purpose of the experiment was to inspect the microstructure, the shape and size of the grains for different samples. The experiment was performed with optical microscope which is not as precise as electronic microscopes but very easy to use and the results can be achieved much faster.

3. MATERIALS SELECTION

To manufacturing the bucket teeth for hydraulic excavator, we used the medium carbon steel and medium alloy steel. Medium carbon steel is characterized by good weld ability, good machinability, and high strength and impact properties in either the normalized or hot-rolled condition.

Medium carbon steel could be treated with heat treatments such as heating, quenching, and tempering to increase the mechanical properties. Table 1 show the chemical composition of materials in this research.

Table 1. Chemical composition of materials

Materials	% C	% Cu	% Mn	% P	% Cr	% S	% Si
Composition	0.6	0.05	0.762	0.112	1.424	0.04	0.966

4. EXPERIMENTAL PROCEDURE

This research paper is done to possess the optimal properties of the bucket teeth, by testing the various processes of heat treatment, hardness test and microscopic examination.

4.1. Heat treatment

The three steps of heat treatment process are heating, quenching and tempering as shown in table 2.

4.1.1 Heating

Heating is one of heat treatment process to harden the steel. This process was done in furnace by heating the steel at certain temperature over recrystallization temperature. The temperature was maintained for specific duration to ensure the uniformity of heat and the change of carbon to austenite phase.

Firstly, the muffle furnace is opened to get the required temperature for heating to harden.

The first four test specimens are placed in the muffle furnace with the heating temperature 850 °C for 1 hour and the other four test specimens are placed in the muffle furnace at the heating temperature 900 °C for 1 hour for hardness test and for examine the microstructure.

4.1.2 Quenching

Quenching is a process of cooling a metal at a rapid rate. This is most often done to produce a martensite transformation. In ferrous alloys, this will often produce a harder metal.

Subsequently, the test specimens were removed from the furnace and quenched by using the appropriate cooling media. I was used the four quenching mediums, they are air, water, salt water and oil. The salt water has the 20% salt. Air, water, salt water and oil can be used to cool the hot steel with fast cooling speed.

Two of the first eight test specimens at the heating temperature 850 °C are placed in the air, the second two are dipped into the water by slowly, the third two are quenched in the salt water by slowly and the last two are dipped into the oil by slowly for cooling for hardness test.

Similarly, heating eight test specimens at the heating temperature 900 °C are quenched in the above four quench media for microscopic examination.

Table 2. Heat treatment of eight specimens

No.	**Specimen**	**Heating temperatures (°C)**	**Holding Time (minutes)**	**Quenching medias**	**Tempering Temperature (°C)**
1	1	850	60	Air	200
2	2	850	60	Water	300
3	3	850	60	Salt Water	400
4	4	850	60	Oil	500
5	5	900	60	Air	200
6	6	900	60	Water	300
7	7	900	60	Salt Water	400
8	8	900	60	Oil	500

4.1.3 Tempering

After quenching, medium carbon steels becomes brittle, develops non-visible micro-crack and it strained due to internal stress. These undesired symptoms are reduced by tempering. Tempering is an essential operation that has to be performed after quenching.

In the tempering process was done for the specimens at the temperature of 200 °C, 300°C, 400°C and 500 °C for 30 minutes in the muffle furnace. Because we used the four tempering temperature, the cooling rate of various quenching media are differ. Two specimens, which are quenched in the air, are placed in the muffle furnace at the tempering temperature 200°C for 30 minutes. The next two specimens, which are quenched in the water, are placed in the muffle furnace at the tempering temperature 300°C for 30 minutes.

The other two specimens, which are quenched in the salt water, are placed in the muffle furnace with the tempering temperature 400 ℃.The last two specimens, which are quenched in the oil, are place in the muffle furnace with the tempering temperature 500℃.

4.2 Hardness Test

The equipment used in this experiment is the Rockwell hardness tester, model (HR 1), serial 11131. The Rockwell hardness tester model (HR 1), serial 11131 has different scales of measuring the hardness of a material and is generally used in laboratory tests. The specimens used for the experiment are high speed steel, mild carbon steel and aluminum. And the scales that are used in measuring the hardness of these materials are Rockwell Hardness scales of HRC and HRB.

HRC scale's experiment will be performed therefore the indenter is changed to a diamond cone. Then a selected specimen is placed on the plate. Then the handle arm rotator is rotated till the point the reading in the display is changed. After the first change in the display, the rotator must be rotated with care to the reading '0' the indicator 'Hi', 'Lo' and 'Ok' helps the user to reach the zero reading with ease. Then the tip barrier on the hardness number indicator is pulled towards the user up to tough the magnifier. After that the handle rotor is rotate with the force is 150kg for high hardness steel. We can read the hardness number HRC after 8 second on the hardness number HRC indicator

Similarly, for each different material specimen the Hardness test of HRC will be repeated 3 times. And for each time the readings will be recorded.

4.3. Microscopic Examination

Firstly, we need to do the specimen preparation process for examine the microstructure of the various specimens in microscope.

4.3.1 Specimen Preparation.

The metallographic specimen preparation process for microstructural investigations of various steel specimens usually consists of five stages: sampling, mounting, grinding, polishing, and etching with a suitable etchant to reveal the microstructure. Each stage presents particular problems in the case of steel. Of course, the graphite phase is studied after polishing and before etching.

4.3.1.1 Sampling

Sampling is the first step-selecting the test location or locations to be evaluated metallography. Usually, steel castings have a considerable variation in microstructure between surface and core. Selection of the test location is very important to obtain representative results from the microstructural examination.

Samples can be obtained by cutting them out from either a large or small casting or from standard test bars, such as micro slugs, ears, or keel bars; however, the microstructure of these pieces may not be representative for the actual casting due to substantial differences in the solidification rates.

4.3.1.2 Mounting

Steel specimens can be mounted in a polymeric material using mounting procedures. The mounting resin is chosen depending on the steel hardness (soft or hard) and the need to enhance edge retention. Use of an incorrect resin, or ignoring the mounting process, can make it very difficult to obtain properly polished graphite in the area close to the specimen edge.

4.3.1.3 Grinding and Polishing.

To ensure proper graphite retention, the use of an automated grinding-polishing machine is recommended over manual preparation. The automated equipment makes it possible, in comparison to manual specimen preparation, to properly control the orientation of the specimen surface relative to the grinding or polishing surface, to maintain constantly the desired load on the specimens, to uniformly rotate the specimens relative to the work surface, and to control the time for each preparation step. Proper control of these factors influences graphite retention, although other factors are also important.

The speed of the grinding-polishing head was 150 rpm, and it was constant. The speed of the platen during grinding was always 300 rpm, and during polishing was always 150 rpm. After each grinding step, the specimens were washed with running tap water and dried with compressed air, while after each polishing step, they were washed with alcohol and dried with hot air from a hair dryer.

4.3.1.4 Etching.

The examination of the steel microstructure with a light optical microscope is always the first step for phase identification and morphology.

To see the microstructural details, specimens must be etched. Etching methods based on chemical corrosive processes have been used by metallographers for many years to reveal structures for black-and-white imaging. Specimens of steels containing ferrite, pearlite, sorbite, cementite, martensite, and bainite can be etched successfully with nital at room temperature to reveal all of these microstructural constituents. Usually, this is a 2 to 4% alcohol solution of nitric acid (HNO_3) ferritic annealed steel with uniformly etched grain boundaries of ferrite and a small amount of pearlite. Nital is very sensitive to the crystallographic orientation of pearlite grains.

5. RESULTS AND DISCUSSION

Rockwell hardness tester was used to take the hardness test and the eight test specimen diameter and thickness are 0.5 inch and 0.75 inch. The indenter is diamond cone (Brale) with the load 150 kg. The eight test specimen hardness test results are shown in table 3.

Table 3. Result of the hardness test

Specimen	1	2	3	4	5	6	7	8
Mean Hardness Number (HRC)	11	31	21	12	17	39	35	24

The microstructures of eight specimens are shown in figure(1), figure(2), figure(3), figure(4), figure(5), figure(6), figure(7) and figure(8) by using the Nikon NV 100 motorized microscope with episcopic/diascopic illumination, which meets the various needs of observation, inspection, research, and analysis across a wide range of industrial fields.

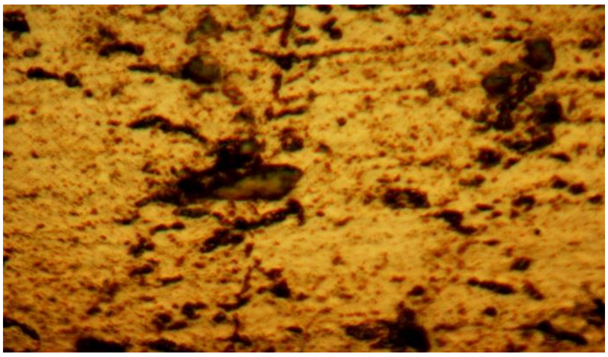

Figure1. Microstructure of sample 1, Heating Temperature 850 ℃, Air quenching & Tempering Temperature 200 ℃, 1500X

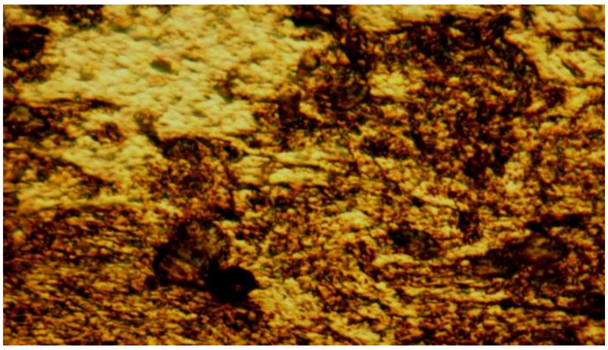

Figure2. Microstructure of sample 2, heating temperature 850 ℃, water quenching & tempering temperature 300℃, 1500X

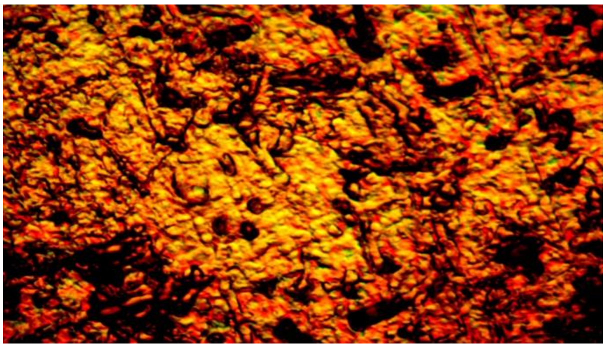

Figure3. Microstructure of sample 3, heating temperature 850 ℃, salt water quenching & Tempering Temperature 400 ℃, 1500X

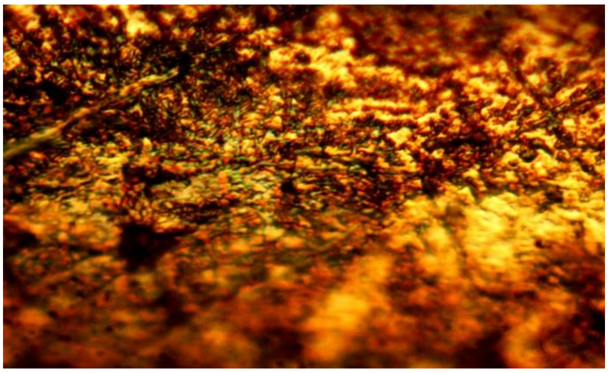

Figure4. Microstructure of sample 4, Heating Temperature 850 ℃, Oil quenching & Tempering Temperature 500 ℃, 1500X

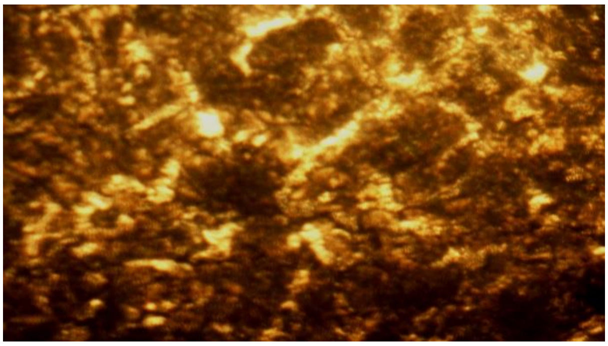

Figure5. Microstructure of sample 5, heating temperature 900 ℃, Air quenching & Tempering Temperature 200 ℃, 1500X

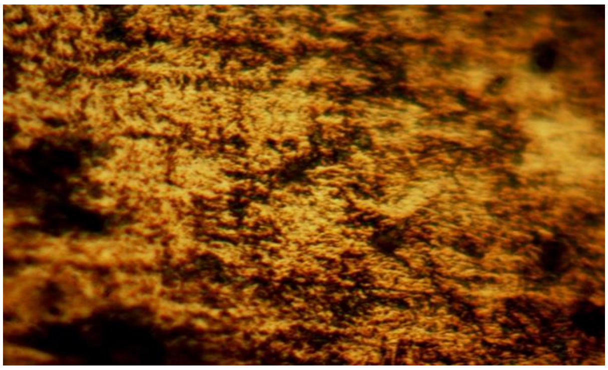

Figure6. Microstructure of sample 6, Heating Temperature 900 ℃, Water quenching & Tempering Temperature 300 ℃, 1500X

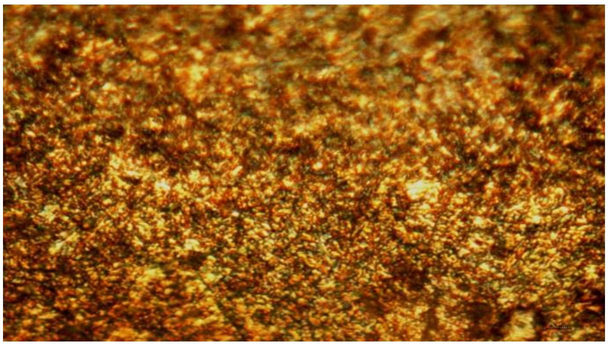

Figure7. Microstructure of sample 7, Heating Temperature 900 ℃, Salt Water quenching & Tempering Temperature 400 ℃, 1500X

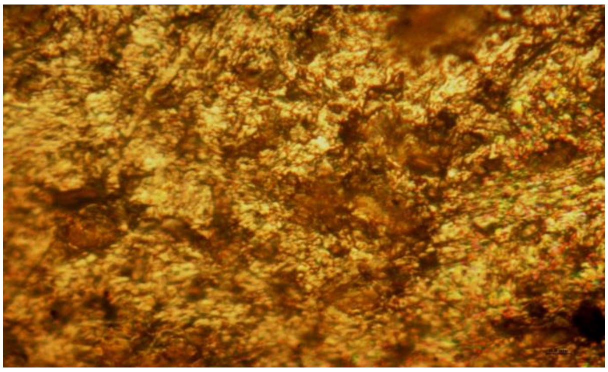

Figure8. Microstructure of sample 8, Heating Temperature 900 ℃, Oil quenching & Tempering Temperature 500 ℃, 1500X

Table 4. Structure and properties from the result of microscopic examination by handbook

Specimen	Structure	Properties
1	Parlite+Martensite	Good hardness and Brittle
2	Secondary Troostite	a little low hardness -low brittleness
3	Cementite+Ferrite	Good Ductility
4	Coarse Martensite	Low hardness and low impact
5	Martensite + ferrite	High hardness &low toughness
6	Martensite	High hardness & brittleness
7	Sorbite	Medium Hardness and high toughness
8	Cementite+ Ferrite	Good ductility

6. CONCLUSION

In the research, the various heat treatment processes of the medium carbon steel for bucket teeth of the hydraulic excavator , the highest value of hardness is 39 HRC can be obtained in the sample 6,with the heating temperature is 900 ℃ , quenching media is water and tempering temperature is 300 ℃ . The second highest value of hardness is 35 HRC in sample 7. That heat treatment process with the heating temperature is 900℃, quenching media is salt water and tempering temperature is 400℃.

From the research, the optimum properties of hardness and microstructure are the test specimen (7), because the hardness number is second highest and it has the sorbite structure. The specimen (6) has the highest value of hardness but that microstructure has the martensite structure, so that this specimen has the highest value of hardness but it has the brittle properties.

So, we should use the process of the heat treatment to catch the optimum properties with the heating temperature at 900℃ , quenching media is salt water and tempering temperature is 400℃.

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