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Microstrucural Investigation and Network Analysis for Austempering Process Using a Blend of Palm Kernel Oil and Bitumen on High Carbon Steel and Ductile Iron

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Abstract Austempering is a multifarious process that starts with austenitizing, followed by rapid cooling and holding so as to prevent formation of pearlite at a temperature above that at which martensite formation starts, until the desired microstructure is formed. To evaluate the cost and time management of using a blend of palm kernel seed oil and bitumen for austempering process in local heat treatment industries, CPM and PERT are used for analyzing the project through project network analysis. The research created a model for determining the order in which activities should be carried out. This gave the optimal time for the duration of the project as 16 days. It is therefore recommended that a blend of palm kernel seed oil and bitumen be used for austempering process in local heat treatment industries, since it is cost and time effective in comparison to salt and molten bath.

Keywords: *austempering, palm kernel seed oil, bitumen, microstructure, hardness, CPM and PERT*

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1. Introduction

Steel is basically an alloy of iron and carbon. It contains less than 2% carbon, controlled amounts of manganese, phosphorous and sulphur. Steels are among the relatively few engineering alloys which can be usefully heat-treated in various ways in order to vary their mechanical properties and widen their engineering application. Heat treatments can be applied to steel not only to harden it but also to improve its strength, toughness or ductility. The type of heat-treatment used is governed by the carbon content of the steel and its subsequent application. Heat treatment processes applied to steels include: normalizing, quenching, martempeing, austempering and stress relieving. Austempered ductile cast iron is a kind of iron that went through special heat treatment process so as to produce mechanical properties that are superior to conventional iron. It is principally characterized by the mixture of pearlite and ferrite [1], while austempered ductile iron has unique matrix of acicular ferrite and carbon stabilized austenite called aus-ferritic (bainite) [2].

Research [3] has shown that there could be reduced project completion time by crashing some of the processes where they brought in additional resources for activities along the critical path of the network. It depicts creation of a computer simulation model to determine the order in which activities should be crashed as well as optimal crashing strategy for a PERT network to minimize the expected value of the total cost given a specified penalty function for late completion of the project. Report [4] has presented an analysis of the CPM and PERT in project planning. The researcher highlighted the means by which a network diagram is constructed from a list of project activities and the computation involved for each method. The scientist solved problems using PERT and CPM and compared the results obtained, hence stating the advantages and disadvantages of each method. The research paper derived from this work presents a framework for reducing total project time during quenching of steel at the least total cost by looking at the steps involved in quenching the steel, thereby optimizing the resources available in order to increase profits and revenues when the quenched steel is used for production. This invariably increases efficiency and productivity.

Some researchers have worked on oil as austempering media, but cracks were found on the specimen though it improved the mechanical properties of the steel. The improved mechanical properties resulting from the austempering process occurred at higher holding time, implying much higher cost. The salt bath furnace and the salts are usually imported and the other quenchants used improved the mechanical properties but not to the required standard.

Bitumen and palm kernel seed oil blend has been identified as a quenchant that is capable of producing full austenitization at reduced holding time and cost without attacking the quenched sample. Therefore, the quenchant could be adapted as a good austempering media. This research aims at evaluating the cost and time analysis involved in using a blend of palm kernel seed oil and bitumen as austempering media. A model will be generated to help solve hypothetical data of a hypothetical project using simulation approach. The method to be used is CPM and PERT for the network analysis. This method was chosen because it is (i) a powerful coordinating tool for planning, scheduling and controlling of quenching process. (ii) It helps to effectively utilize resources available and in minimization of effective resources during the quenching process. (iii). Helps in minimization of delays and interruption during implementation of the project.

2. Materials and Methods

High carbon steel and ductile cast iron were used as test samples to evaluate palm kernel seed oil and bitumen blend as austempering media. The chemical composition of the alloys is shown in the table below. The equipment used during the experiment were: electrically heated furnace with temperature 1200°C, medium sized kerosene stove and pot for heating the palm kernel seed oil, struner's hot mounting press for mounting all metallographic samples, laboratory mercury thermometer, weighing balance, starter pH meter, H_2SO_4 and HCl, spectrophotometer.

Table 1. Chemical composition of the steel and ductile cast iron

Element	C	Mn	Si	S	P	Fe
0.76%C	0.76	1.11	0.33	0.03	0.05	Fe
Ductile cast iron	3.65	0.34	2.28	0.02	0.03	Fe

Palm kernel seeds were purchased from local palm processors in Ekwuluobia, Anambra state. Palm kernel oil was extracted from the palm kernel seeds using the traditional method of heating and pressing. Bitumen was purchased from C & O civil engineering laboratory Awka, Anambra state. Laboratory thermometer was placed into the steel pot containing the palm kernel seed oil and bitumen blend, and then heated to its boiling temperature. One sample each from the alloys was taken out as control (as untreated) before heating the other ones. The remaining samples were given a normalizing heat treatment by heating the samples in an electrical furnace at various temperatures starting from 840°C to 960°C, soaked at various time intervals ranging from 0min to 1 hour, removed and cooled in air. One sample each was taken and kept aside as normalized sample. Normalized samples of 0.76%C-steel were taken and placed in a crucible, loaded into the furnace, heated to 900°C , soaked for one hour and quenched in a blend of hot kernel seed oil and bitumen boiling at temperature of 420°C. After some minutes, the first set of samples were removed from those quenching medium, cooled in air and washed in kerosene, then with soap solution. Another set of samples were removed after 0 minute, 30 minutes, 1 hour, cooled in air and washed in kerosene then in soap solution. Bitumen was added in a small quantity to avoid under reaction or over reaction.

2.1. Metallographic Samples Preparation for Microstructure.

All the samples both untreated and heat treated involved in this experiment were subjected to thorough metallographic sample preparation processes highlighted thus

(a) Rough machine grinding of all samples successively on 60, 80, 120 and 180 gritts abrasive emery grinding papers.

(b) Fine machine grinding of all samples on 200, 400 and 600 gritts abrasive emery papers using wet type process.

(c) Polishing all the ground samples on a polymet polishing machine.

(d) Testing polished samples for hardness at three different points on the same surface of metal sample and the average was taken.

(e) Re-polishing all samples after the hardness test and then etching them.

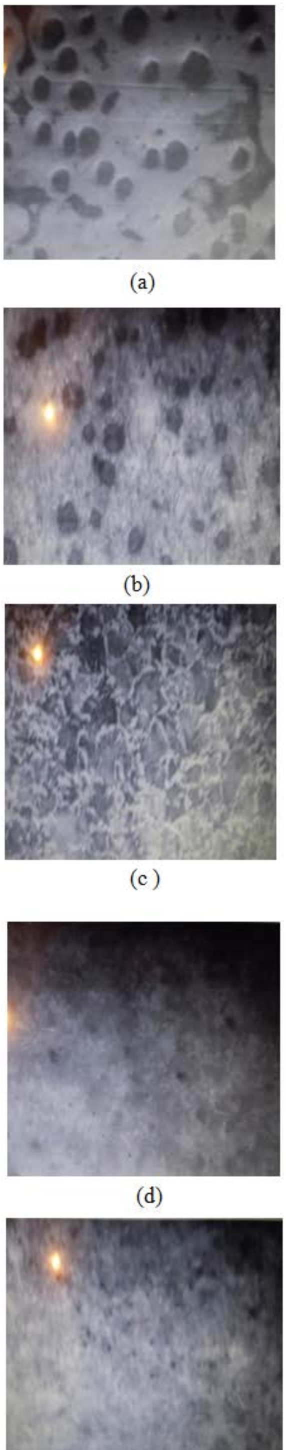
2.2. Melting

Melting was carried out in an induction furnace with charge capacity 250kg. After melting, the melt was transferred into a ladle so as to produce the alloy. Melted material was poured into the prepared sand mould and allowed for solidification.

3. Results and Discussion

3.1. Micrographs of Austempered Steel and Cast Iron Quenched in a Composition of Kernel Seed Oil and Bitumen.

Microstructural examination of the treated and untreated samples was carried out. Each sample was carefully ground progressively on emery paper and the grinding surface of the samples were polished on a micro cloth. The crystalline structure of the specimens was made visible by etching on the polished surfaces. Microscopic examination of the etched surface of various specimens was carried out using metallurgical microscope. The structure of as-received 0.76%C-steel shows ferrite in pearlite matrix while that of the as-cast ductile cast iron shows pearlite with ferrite. The micrographs of the sample quenched in bitumen and kernel seed oil blend from 0 minute to 60 minutes shows that in both steels, at the initial austempering time, combination of retained austenite and martensite were obtained but for high values of austempering times and at various austenitizing temperatures, a mixture of retained austenite and bainite was also obtained. It was also assumed that the low distribution of martensite at lower soaking time is caused by the short heating times resulting in a non-homogeneous austenite. This shows existence of concentration gradient and diffusion of carbon into the austenite phase. With increasing austempering time, however, carbon diffusion is enhanced and a more homogeneous austenite evolved resulting in higher martensite transformation distribution upon quenching. At the initial period of austempering, a mixture of martensite and retained austenite was obtained. However as the austempering time increased, bainite (ausferrite structure) was formed along with some retained austenite. The same structure also formed as the austenitizing temperature increased for the same austempering time and the same quenching media. The different microstructures observed are as a result of the different cooling rates at different austenitizing temperatures. It has also confirmed that the above heat treatment process is realistic and reliable for the development of structures with improved mechanical properties comparable to those of austempered samples.



(e)

Figures 1. Microstructures of (a) unquenched ductile cast iron (b), (c), (d) and (e) ductile cast iron quenched in composition of palm kernel seed oil and bitumen

(j)

Figures 2. (f) – (j) Shows the microstructure of 0.76%C-Steel; figure (f) shows the structure of unquenched 0.76%C while figures (g,) (h), (i), and (j) show the microstructure of 0.76%C Steel quenched in a composition of palm kernel oil and bitumen

3.2. Network Analysis

The CPM strategic planning process for planning and development of quenching process of steel was studied in order to obtain the optimal time at minimum total cost in order to complete the implementation of project. The research which enables the project management study analyzed the value of project activity during all phases of the project so as to reach the maximum benefit and minimum cost planning. This was achieved by developing modules that allow assessing activities and resources that may be critical through drawing project network, which may affect the project and its finish date at normal and crash time.

3.2.1. Scheduling of the Quenching Process for Crashing Time

The scheduling for the quenching process is investigated for improvement thereby reducing the time [5]. The schedule analysis project activities consist of seven (7) different activities including different works as shown in Table 2. The process is simulated to reveal its critical path, which identifies the activities that determine the overall completion time required by the process. The analysis of the project is used to formulate an estimation of the time to recovery and assess the efficiency of the schedule of repair activities. An evaluation of the trade-offs between the time to recovery and resource investments is used to investigate how costly project delays can be avoided.

3.2.2. Requirements for Quenching of the Steel

The defined activities for the quenching of the steel include:

(1) Material identification, selection/purchase of the medium carbon steel
(2) Cutting of the material purchased.
(3) Machining of the material to the particular impact, hardness and tensile strength measurement/dimension.
(4) Preparatory process for the heat treatment of the steel/preparing the materials needed for the heat treatment process.
(5) Quenching of the steel
(6) Polishing of the quenched steel for microstructure investigation.
(7) Mechanical testing process.

Table 2. The scheduled analysis of the activities of the quenched steel

No	Activity	Activity Description	Predecessors	Time activity (days)
1	A	Material Identification/purchase	-	4 days
2	B	Cutting of material purchased	A	3 days
3	C	Machining of the material to specific dimension	A	2 days
4	D	Preparatory process/preparing the materials needed for the heat treatment & quenching starts	B	5 days
5	E	Quenching of the steel	B	3 days
6	F	Polishing of the quenched steel for microstructural investigation	C,D	4 days
7	G	Mechanical testing process	E,F	3 days

3.2.3. Network Representation of the Activities during Quenching of Steel

From Figure 3, line D_1 and D_2 are two dummy activities used to maintain the logical sequence.

The project and activities of the quenched steel is as shown in the network. The network is a graph showing each activity to be performed, its predecessor and successor/activity (represented by an arrow).

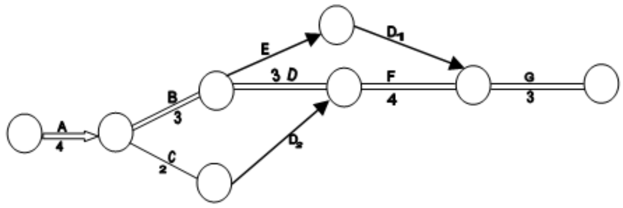


Figure 3. Network diagram for scheduled quenching of steel

3.2.4. Establishment of Critical Path for the Activities during Quenching of Steel

The minimum time needed for the completion of the activities during the quenching process and the paths followed is called the critical path [6]. The method to follow is to sum all the activities with no slack time. Slack is determined by finding the earliest start and finish time. Earliest time of an activity can be started when all preceding activities are completed as quickly as possible. Earliest finish time is earliest starting time + time of the activity. From the network diagram, the ES, EF can be obtained by moving forward in the network and LS, LF by moving backward in the network.

$$EF = ES + t \tag{1}$$

$$LF = LS + t \tag{2}$$

$$\text{Hence slack} = LS - ES \tag{3}$$

$$\text{Slack} = (ES + t) - (LS + t) \tag{4}$$

Table 3. Slack time analysis of the activities during the quenching of steel

Activity	Activity Time	ES	EF	LS	LFT	Slack
A	4	0	4	0	4	0
B	3	4	7	4	7	0
C	2	4	6	8	12	4
D	5	7	12	7	12	0
E	3	7	10	9	12	2
F	4	12	16	12	16	0
G	3	16	19	16	19	0

Figure 3 indicates that the critical path is the path that connects the activities with zero slack, which can be determined. Based on the foregoing, the critical paths from the figure is A-B-D-F-G.

3.2.5. Cost Analysis of the Project

Table 4. Cost analysis of the activities during the quenching of the steel

No	Activity	Activity Description	Cost (N)
1	A	Material Identification/purchase	8,000
2	B	Cutting of material purchased	2,000
3	C	Machining of the material to specific dimension	10,000
4	D	Preparatory process/preparing the materials needed for the heat treatment	-
5	E	Quenching of the steel	25,500
6	F	Polishing of the quenched steel for microstructural investigation	3,200
7	G	Mechanical testing process	10,000

From Figure 3, the critical path is A-B-D-F-G = 4+3+5+4+3 = 19 days.

Direct cost of the project can be determined from Table 4: A-B-D-F-G = #58,700.

Indirect cost of the project = 19 × 50 = #950

Total project cost = # (58,700 + 950) = #59,650

The optimal values for the date of completion of the project and the money involved for the project is stated below:

$$f_1(x) = \mathrm{T} - 16;$$

$$f_2(y) = \mathrm{M} - 58{,}000;$$

$$\mathrm{F} = \max\left[f_1(x), f_2(x)\right].$$

4. Conclusions

Following microstrucural investigation and network analysis for austempering process using a blend of palm kernel oil and bitumen on high carbon steel and ductile iron, it was concluded that quenching of high carbon steel and ductile cast iron with palm kernel oil and bitumen blend is cost effective and is therefore recommended to local heat treatment industries in the area of austempering for adoption. This is because scope, cost and time management are important variables for projects, since every successful project is characterized by sound project analysis using some form of network diagram that breaks up even very massive projects into small and manageable discrete tasks that can be performed. Furthermore, palm kernel seed oil and bitumen blend is a good austempering media since specimens quenched in it are devoid of cracks.

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