The Effect of Thermomechanical Ageing of Aluminium-Copper Alloy (MATLAB Approach)

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SIMULATION AND MODELING OF A CARBURIZING PROCESS USING VARIABLES FOR EFFECTIVE PERFORMANCE IN SERVICE IN AISI 1032 STEEL

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ABSTRACT

The mechanical properties of AISI 1032 steel samples carburized in Wood Charcoal and Snail Shell were investigated. The samples were modeled and simulated using Fick's law and C++, in order to evaluate the performances of solid carburizing media on the mechanical properties of steels at different conditions. The results revealed that the case depth, tensile strength and hardness values of samples carburized with Wood Charcoal (WChl) are higher compared to those carburized with Snail Shell (SS) at 800 ^{0}C and 950 ^{0}C respectively. These were evidently substantiated with their micrographs as observed under DV-500 Version 10.2 Metallurgical Microscope with X500 magnification. The case-depth is directly proportional to the carburized temperature and time. It was concluded that Fick's law is good at predicting the diffusion of carbon in steels.

INTRODUCTION

Carburization is the process by which carbon is diffused into the surface of steel in order to increase its hardness. The carbon forms carbide precipitates (particularly if the steel contains carbide forming elements such as manganese or molybdenum) which pin dislocations and prevent slip, thus making the material harder. Carburizing is a case-hardening process in which carbon is dissolved in the surface layers of a low-carbon steel part at a temperature sufficient to render the steel austenitic, followed by quenching and tempering to form a martensitic microstructure. The resulting gradient in carbon content below the surface of the part causes a gradient in hardness, producing a strong, wear-resistant surface layer on a material, usually low-carbon steel, which is readily fabricated into parts [1].

However, the increased carbon content reduces the toughness of the material. This is because the carbon sits in the interstitial sites of the lattice structure and hinders the movement of dislocation lines. In most applications it is important that the surface of the steel is hard, but the core material can remain softer without detriment to the properties of the component. Thus, carbon is often diffused in from the outer surfaces to obtain a material that is hard on the surface but tough in the core.

Diffusion is the process by which mass flows from one place to another on an atomic, ionic molecular level. It can also apply to the flow of heat within bodies. When dealing with a solid, diffusion can be thought of as the movement of atoms within the atomic network, by "jumping" from one atomic site. In order for there to be a net flow of atoms from one place to another there must be a driving force; if no driving force exists, atoms will still diffuse, but the overall movement of atoms will be zero, as the flux of atoms will be the same in every direction. Picture an impurity atom in an otherwise perfect structure. The atom can sit either on the lattice itself, substituted for one of the atoms of the bulk material, or if it is small enough, it can sit in an interstice (interstitial). These two positions give rise to the two different diffusion mechanisms.

However, the study focuses on the determination of diffusion flux (D) (mol/m^2s); diffusion coefficient (D_0) (m^2/s); activation energy (Hd) as well as the microstructure at elevated temperature as means of evaluating the performance of the carbon source using C++ programming language. The effectiveness of varying temperature and time on wear resistance and case depth of carburizing material would also be ascertained. The combined effects of time, temperature, and carbon concentration on the diffusion of carbon in austenite can be expressed by Fick's laws of diffusion [2].

MATERIALS AND METHODS

Materials

AISI 1032 steel samples were used in this work. Carburizing Media used are Wood Charcoal (WChl) and Snail Shell (SS), Rockwell Hardness and Tensile Testing Machines, Grinding and Polishing machines, Metallurgical microscope as well as C++ software were used.

Methods

AISI 1032 steel samples (200mm Length and Φ16 Diameter) of 0.32% carbon were used in this work. 16 out of the 20 samples were prepared and carburized using two carburizing media. The remaining 4 were reserved as control samples. Two different carburizing media (Snail Shell and Wood Charcoal) used in this research, were grinded to fine sizes (powdery form) by milling machine and sieved to separate dust and other unwanted particles. Each powdery carburizing media was mixed in appropriate proportion with binder and energizer (Barium Carbonate). The specimens were pickled and cleaned before burying into carbon-rich mixture in a 3 layer rectangular box made from mild steel. The bottom of the rectangular carburizing box was covered with the carburizing mixture of about 20-30mm deep before burying the samples and preheated in an electric furnace at a temperature of 400^0C for an hour.

$$BHN = \frac{F}{\frac{\pi}{2} D \cdot \left(D - \sqrt{D^2 - D_i^2}\right)}$$

Equipment Used

Fig1: Tensile tester

fig 3: Polishing

fig.5: Microstructural Analysis Set-up

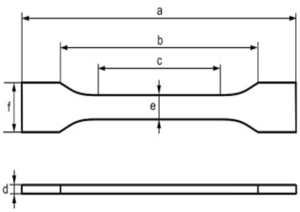

Fig 2: Tensile test specimen

Fig 4: Hardness and microstructural test sample

Fig 6: Furnace

a = 75mm b = 50mm c = 40mm d = 8mm e = 4mm f = 8mm

Then, the carburized samples prepared were austenised separately in each medium at temperature ranging from 800°C-950°C for say six hours (2-6 hrs). The samples were quenched in water and tempered at 350°C for one hour to relieve the induced stresses in the samples. Spectrochemical analysis was later carried out to obtain the chemical composition of the samples (Table 3.1). In addition Mechanical tests were also carried out in order to obtain the tensile strength and hardness of both carburized and control samples. The work was modeled using Fick's law and simulated using C++ to compare its obtained result with those obtained from the experimental approach.

The carburized samples obtained after heat treated in the furnace shown in Fig 6 were machined to tensile test gauge samples (as in Fig. 2) and were later fixed in the tensile testing machine shown in fig 1 to obtain the tensile strength of the carburized steel samples. Another set of carburized samples were machined into hardness and microstructural test samples (Fig .4), these were later placed on the polishing machine (Fig. 3) to prepare the sample surface for etching and subsequent clarity of phases. The polished samples were later subjected to microstructural examination using the microstructural set up shown in fig. 5.

C++ Programming Language

C++ is a world-class programming language for developing industrial-strength, high-performance computer applications. It evolved from C, which evolved from two previous programming languages, BCPL and B. BCPL was developed in 1967 by Martin Richards as a language for writing operating-systems software and compilers for operating systems [3]. C++ provides a collection of predefined classes, along with the capability of user-defined classes. The classes of C++ are data types, which can be instantiated any number of times. Class definitions specify data objects (called data members) and functions (called member function). Therefore, it is mainly used for Software Engineering and Graphics.

Spectrochemical Analysis

The specimen sample (AISI 1032 Steel) was obtained from Universal Steels Limited, Ikeja, Lagos, Nigeria. The obtained results are presented here.

Table I: Spectrochemical Analysis (AISI 1032 steel)

No./Element	C	Si	Mn	S	P	Cr	Ni#1	Cu#1	Nb
1	0.325	0.230	0.770	0.054	0.042	0.124	0.097	0.356	<0.0001
Avg	0.3250	0.2300	0.7700	0.0540	0.0420	0.1240	0.0970	0.3560	0.0001
No./Element	Al#1	B	W	Mb	V	Ti	Fe		
1	<0.0001	0.001	<0.0001	<0.0001	<0.0001	0.010	97.991		
Avg	0.0001	0.0010	0.0001	0.0001	0.0001	0.0100	97.9910		

RESULTS AND DISCUSSION

Determination of Activation Energy (Hd)

The results are presented as shown Figs.7.1-7.7. The curves were plotted as logarithmic function (InD) of diffusion co-efficient against the absolute temperature (T/Kelvin). The slope so formed produced the activation energy necessary for the diffusion of carbon into the surface of the sample AISI 1032 Steel.

From equation combining Fick's first and second law to give the rate of diffusion:

$$D = D_0 \exp\left\{\frac{-Hd}{kT}\right\} \tag{1}$$

Where: D = Diffusion co-efficient (mm/hr)

D_0 = Temperature-independent pre-exponential (mm²/s)

K = The universal gas constant (8.31 J/mol-k)

T = Absolute temperature

Hd = Activation Energy

From Activation Energy, Determination of Pre-exponential

$$D/D_0 = e^{-\left\{\frac{H}{kT}\right\}} \tag{2}$$

$$\mathrm{In}\ D/D_0 = -\left\{\frac{H}{kT}\right\} \tag{3}$$

$$\text{In}\, D - \text{In}\, D_0 = - \left\{ \frac{H}{kT} \right\} \quad (4)$$

$$\text{In}\, D_0 - \text{In}\, D + \left\{ \frac{H}{kT} \right\} \quad (5)$$

Table II: Case depth (100 – HBR) x 0.01

	Case-Depth (C_{sd}) mm for Wood Charcoal				Case-Depth (C_{sd}) mm for Snail Shell			
S/N	Temp (^{0}C)	2.0 hr	4.0 hr	6.0 hr	Temp (^{0}C)	2.0 hr	4.0 hr	6.0 hr
1	800	0.42	0.59	0.67	800	0.38	0.53	0.59
2	850	0.54	0.64	0.76	850	0.50	0.58	0.72
3	900	0.60	0.72	0.88	900	0.54	0.66	0.81
4	950	0.67	0.85	0.96	950	0.63	0.78	0.92
5	1000	0.70	0.90	1.08	1000	0.67	0.84	0.98

Table III: Variation of activation energy (KJ/mol) with pre-exponential (m^2/s)

		Activation Energy (KJ/mol)	Pre-exponential (m^2/s)
Carbon Source	WChl	18.4047	$2*10^1$
	SS	37.9248	$4*10^1$

Graphical Analysis for Case Depth

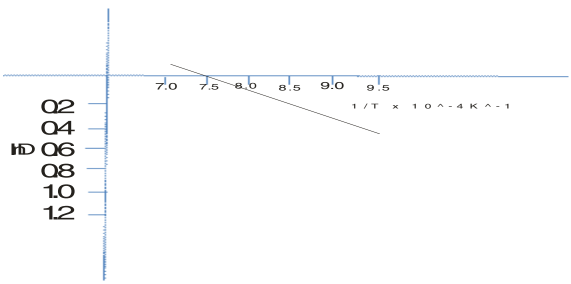

Fig. 7.1: Plot of the diffusion coefficient (InD) with the diffusion absolute Temperature using WChl

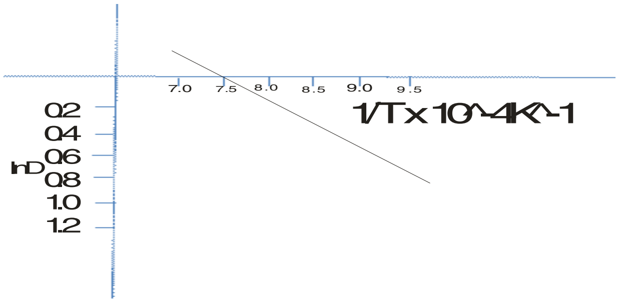

Fig.7.2: Plot of the diffusion absolute temperature for coefficient (InD) with the absolute temperature for SS using

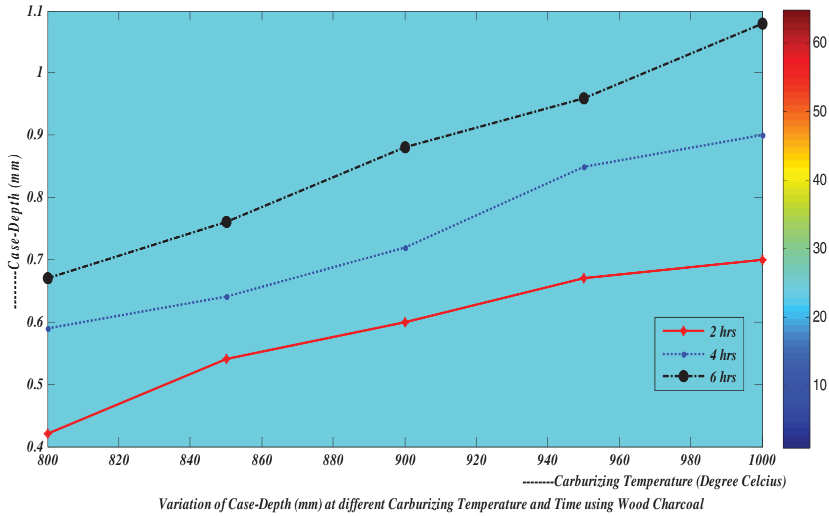

Fig. 7.3: Variation of Case-Depth (mm) Temp. (^{0}C) and Time (hr) using Wood charcoal

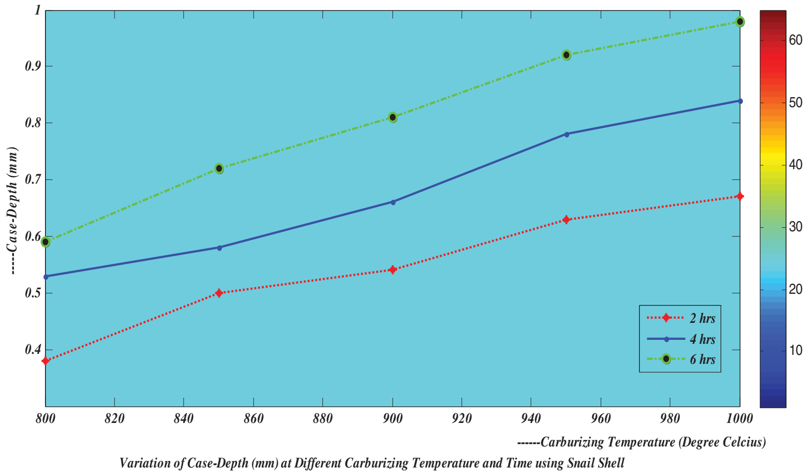

Fig. 7.4: Variation of Case-Depth (mm) at different at different Carburizing Temp. (^{0}C) and Time (hr) using Snail Shell

Mechanical Test Results

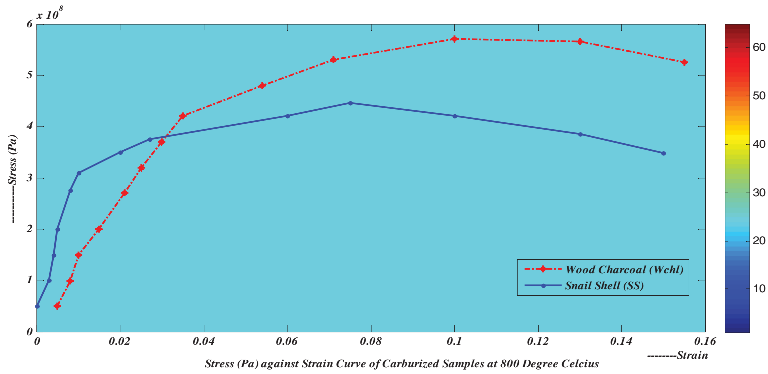

Fig. 7.5: Stress-Strain Curve for Carburized AISI 1032 @ 800^{O}C with WChl and SS

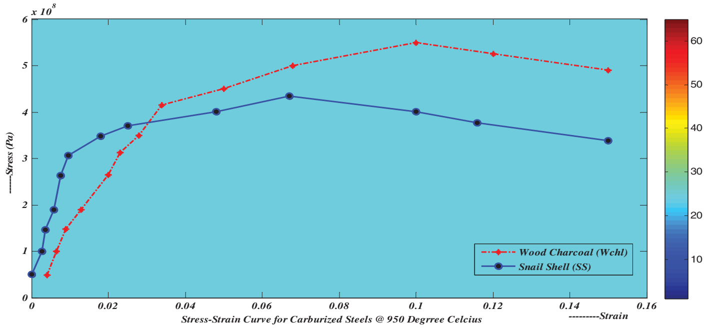

Fig. 7.6: Stress-Strain Curve for Carburized AISI 1032 @ 950^{0}Cwith WChl and SS

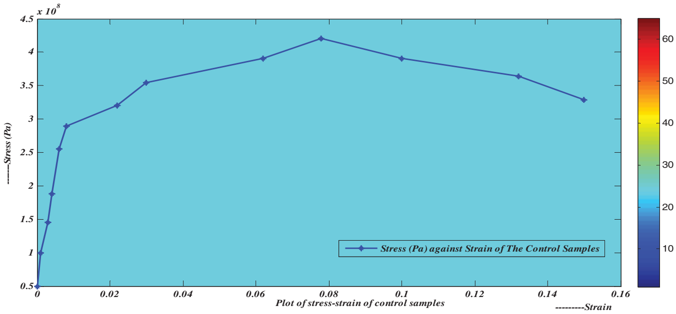

Fig. 7.7: Stress-Strain Curve for Control Sample

Microstructural Test Results

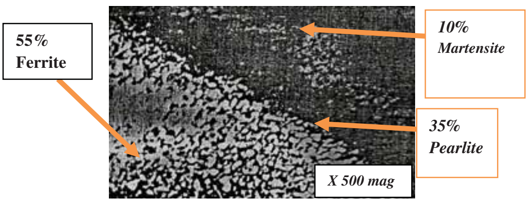

Fig. 8.1: 1032 Steel Carburized using Wchl X 500 mag

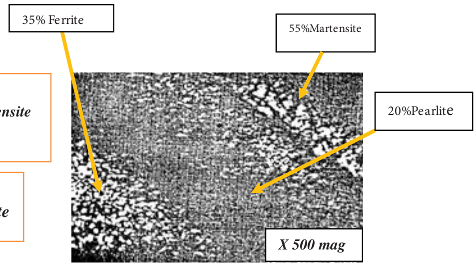

fig. 8.2: 1032 Steel Carburized using SS X 500 mag

DISCUSSION OF RESULTS

Fig. 7.1 and 7.2 showed the plot of the diffusion coefficient (InD) with the absolute temperature for diffusion using SS and WChl. The possibility of WChl displaying a better performance is only due to lower activation energy (-18.4KJ/mol) compared to SS recording 37.9KJ/mol, thereby making it difficult for diffusion process which could have enhanced its performance in service with a hard case and tough core.

The Case depth for the carburized AISI 1032 with WChl is higher compared to those with SS. This is also reflected in Figs.7.3- 7.4 and Table II where case-depth is directly proportional to the carburized temperature and time. However, there is variation in case depth from surface to the center depending on the temperature, severity, viscosity and degree of agitation of the quenchant [4].

Figs. 7.5 and 7.6 showed that the tensile strength is inversely proportional to the carburizing temperature. That is, the higher the carburizing temperature, the lower the tensile strength of the material. In addition, the tensile strength of samples carburized with WChl (570.1 and 550.1 MPa) is higher compared to those with SS (445.2 and 435.2 MPa) at 800^0C and 950^0C respectively. This comparatively shows the relative ease with which carbon diffuses into the part surface for WChl. In other words WChl as a Carburizer will enable the Carburized parts to be tough, that is, hard case and soft core having been tempered to 200^oC for 1 hour. This is evident in the case-depth measurement complemented by the microstructures whose phases were initially conspicuous as ferrite and the pearlite but now transformed at post-treatment as a hard martensite on the case with a retrogressive increase toward the core. The Volutish appearance on the case revealed high case-depth with a decreasing trend towards the core as carbon diffuses through (Fig.8.2).

From Table III showed the variation of activation energy (KJ/mol) with pre-exponential (m^2/s) of the carburized samples. It was observed that SS (37.9248 KJ/mol) samples have higher activation energy than WChl samples (18.4047 KJ/mol). This is an indication that diffusion of carbon is slow in SS than WChl. Therefore, the WChl performs better, than its peers, owing to its ease with which carbon mass will diffuse into the surface of the material. This was possible due to the lower activation energy required to drive the carbon atoms through the section of the component.

The micrographs (Fig.8.1-8.2) revealed that, the hardness reduces progressively until it reaches the core hardness. This necessitated the caution for not grinding the parts excessively, otherwise the resulting surface hardness and strength will be significantly diminished.

CONCLUSION AND RECOMMENDATION

Case hardening treatments offer a means of enhancing the strength and wear resistance of parts made from relatively-inexpensive easily worked materials. Production, absorption and diffusion of carbon are greatly affected by the temperature, time and composition of the carburizing temperature (800^oC -950^oC). This temperature range produces a complete austenite phase in steel and the absorption and diffusion rate are sufficiently high.

Conclusively, comparing all the parameters obtained from the research work using Fick’s law and C++ (which are good at predicting the diffusion of carbon in steels.), it could be inferred that WChl is better than SS in increasing the carbon content of steels.

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C++ PROGRAMMING

```
#include <cstdlib>
#include <iostream>
#include <math.h>

using namespace std;

int main(int argc, char *argv[])
{
  //declaration of variables...

  string cname;
  double d2, d1, t1, t2, k=8.31, d, Do, Hd, DT;
  cout<<"Simulation of Fick's law with the use of C++ programming\n";
  cout<<"Determination of Activation Energy Hd\n";
   cout<<"Enter Carbon Name:";
  getline(cin,cname);

  cout<<"Enter value for D2:\t";
  cin>>d2;
   cout<<"Enter value for D1:\t";
  cin>>d1;

  cout<<"Enter value for T2:\t";
  cin>>t2;

  cout<<"Enter value for T1:\t";
  cin>>t1;
```

```
 d = (((d2 - d1) * k) / ((t2 - t1) * (1 /pow(10, 4)))) / 1000;

 Hd = -1 * d;
//cout<<"Hd = "<<Hd<<"KJ/mol.\n";
cout<<"Determination of Pre-Exponential of "<< cname<<"\n";
 cout<<"Enter value for InD:";
 cin>>d;
 cout<<"Hd = "<<Hd<<" KJ/mol\n";
 cout<<"InD = "<< d<<"\n";
 cout<<"1/T = "<< t2<< " x 10^-4"<<"\n";
 cout<<"K = "<<k<< "J/mol-k"<<"\n";
 Do = d + ((Hd * 1000) * ((t2 * (1/(pow(10, 4)))) / k));
 cout<<"Do = "<<Do<<"\n";
 DT = floor(Do);
   cout<<"Do = "<<DT<< " X 10^1 M^2/S"<<"\n";
 system("PAUSE");
 return 0;
}
```