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Evaluation of Animal Dungs as Alternative Heat-Treating Materials in Foundry Shop

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Abstract
The use of steel in engineering materials is diverse due to its adjustable properties heavily relying on heat treatment process. Properties to fit design purposes and to provide desirable mechanical properties combinations such as ductility, toughness, and hardness are possibilities. The mechanical properties of samples of medium carbon steel are examined after heat treatment using animal dungs as cooling/quenching media. These steel samples were heated at 950°C (above critical temperature, quenching) and soaked for 10 minutes in muffle furnace before cooling in respective media (Cow, Donkey and Horse Dung). The mechanical behaviour of the sample was investigated using Monosanto tensile testing machine for tensile and comprehensive tests and Brinell hardening method for hardness test. The microstructure of these samples was examined using SEM (Scanning Electron Microscope). The experimental result showed that sample heat treated with cow dung have highest ultimate tensile strength, comprehensive and hardness value of 866 MPa, 945.33 MPa and 208 BHN, respectively. Hence, waste cow dung can be used as a potential low-cost heat-treating material in a foundry.

Keywords: *Medium carbon steel, heat treatment, animal dung, quenching, microstructure.*

1.0 Introduction

Steel has been used extensively by mankind. It is an alloy of iron and carbon, with a carbon content that ranges between 0.05% - 2.1% [1]. The production of steel continues to develop more interest among the Engineers due to its economic benefit, especially in developing countries. Heat treatment processes are essential in production of machines gears, farm implement, springs and automobiles etc., which are required to have important mechanical properties such as toughness, hardness and wear resistance. According to [2] studied problems and opportunities inherent in the production of steel in Nigeria and concluded that the problem of low engineering strength characteristics was due to metallurgical process dysfunction. Innovative heat treatment methods can improve the engineering property of steel [3]. Cooling in the right medium can enhance the mechanical characteristics of medium carbon steels [4]. Nonetheless, the primary determinants in selecting the cooling medium are the type of heat treatment, the composition of the steel, and the dimensions and configuration of the components [5]. In industry, water and oil cooling may result in quench cracks, minerals oils exhibit goods cooling capacity for the majority of alloy steel, they are comparatively costly and hazardous [6]. The investigation of mechanical properties of steel in a Nigerian context remains a vital area of research [7]. According to [8] who investigated the effect of cooling rate on the microstructure and mechanical properties of AISI 1050 steel. Using three different cooling medium cold water, hot water and vegetable oil. The result shows that cold water had the highest hardness value. The concept of using biomass as a resource for material science has seen recent exploration, particularly in bio-waste [9, 10]. The use of locally and available materials, such as animal dungs otherwise termed non-useful materials which is readily available and at no cost which has the advantage of lesser risks of cracking [11]. The aim of this research work is to improve the mechanical features of medium carbon steel applicable for fabrication of tools, automobiles, gears, spring and farm implement by the use of animal dungs as alternatives heat treatment material in foundry shop.

2.0 Materials and Methods

2.1 Materials

The materials utilized in this research consist of medium carbon steel, with the chemical composition detailed in Table 1, procured from the Peugeot automobile company Kaduna, Nigeria. The cow dung, donkey dung and horse dung used as cooling media were procured at Minna Niger State, Nigeria.

Table 1: Chemical Composition of the "As –received" Medium Carbon Steel

Element	Composition (%)
C	0.52
Ca	0.62
Fe	93.99
Ni	0.34
Cu	0.45
Zn	1.06
Sb	0.44
Cr	1.53
Tl	0.20
Mn	0.75

2.2 Methods

A set of samples were machined from the as-received medium carbon steel. Sample of the same composition, the specimens were prepared after series of machining operation following the international test standard, as shown in Figure 1. A control samples were kept or machined test samples (for tensile, compressive, hardness and microstructure analysis). The leftover samples were placed in the muffle furnace for thermal processing. The samples were heated to temperature of 950°C above upper critical temperature (910°C) as quenching process. It then holds in the furnace for ten minutes; the test samples were removed from the furnace in a hurry and cooled in their respective cooling media. Microstructure examination of the heat-treated samples was examined and tensile tests, compressive test and hardness values were also carried out on each of the sample.

2.3 Mechanical Test

2.3.1 Tensile Testing

The tensile properties of the cooling medium carbon steel sample were carried out using "MonsoTensometer" of 20 kN capacity. Initial gauge length, width and thickness were taken and recorded. Each of the samples was loaded till fracture occurs, the fracture load of each sample was recorded as final length, width and thickness, equations (1), (2), and (3) were used to calculate the yield strength, tensile strength, and strain from the graph of load against extension that was plotted on graph paper fixed to the stylus.

Yield strength $\delta_y = \frac{P_y}{A_o}$. (1)

where δ_y is the yield strength in N/mm^2, p_y is the yield load in newton, (A_o)is the initial area in mm^2

$$Tensile\ Stress(UTS) = \frac{P_{max}}{A_o} \quad (2)$$

Where P_{max} is the maximum load applied

A_o is the original cross-sectional area.

Tensile stress (N/mm^2) or (mp$_a$)

Maximum load (N)

Initial Area (mm^2)

$$Strain = \frac{l_f - l_o}{l_o} \quad (3)$$

Where $l_f$and l_o represent final guage length (mm) and initial guage length (mm), respectively.

Following the fracture, the specimen's shattered ends were put together, and the final gage length was measured to determine the % elongation using equation (4).

$$\%\ elongation = \frac{\text{final guage length} - \text{Initial guage length}}{\text{Initial guage length}} \times 100 \quad (4)$$

Initial guage (mm)

Final guage length (mm)

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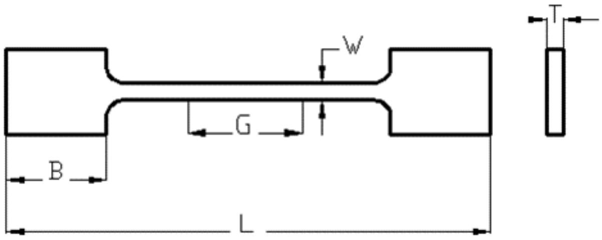

Figure 1: Tensile Test Sample

Where L=150 mm
G= 50 mm
W=3 mm
T= 5 mm
B= 30 mm

2.3.2 Compressive Testing

Similar to tensile test the compressive specimen was climb on the tensiometer through a suitable compressive gauge, after which a load gauge was set to zero the machine is equipped with a compressive device that reverse the tensile pulled of the machine to the compressive load on the specimen. The load was gradually applied on the specimen by turning the hand wheel of the tensiometer until it buckles. The load which buckles the specimen was observed and recorded. The buckles specimen and compression gauge were gently removed from the machine.

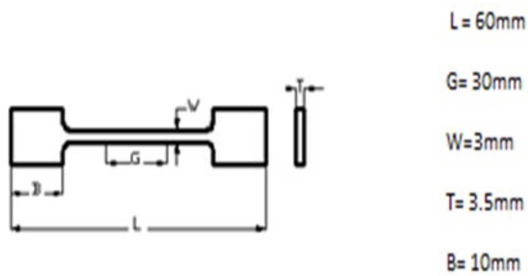

Figure 2: Comprehensive Test Sample

2.3.3 Hardness Testing

Visual Universal Hardness Testing machine was employed for the hardness measurement. Each sample of dimension 40 × 30 mm were placed on the anvil of the machine; after that, the load was applied, leaving the sample with a circular indentation. The Brinell hardness number (BHN) was computed using equation (5):

$$BHN = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)} \tag{5}$$

The applied force (kgf) is represented by P, and the indenter's diameter (mm) is represented by D [7].

3. Results and Discussion

The results of these mechanical properties of sample after cooling in respective cooling media and control sample are tabulated in Table 2. And the graph of stress – stain curves are presented in Figure 3-6.

From Table 2 the result of the yield strength shows that control sample had highest in value of yield strength of 931 MPa and sample cooled in horse dung media had yield strength of 780 MPa followed by cooled in cow dung media had yield strength of 712 MPa while sample cooled in Donkey dung had the least yield strength of 502 MPa. This shows that the control sample can withstand more loads. The tensile strength result shows that the control sample had the highest value of ultimate tensile strength of 1031 MPa, while the sample cooled in cow dung media had ultimate tensile strength of 866 MPa. Sample cooled in horse dung media had ultimate tensile strength of 841 MPa. Sample cooled in Donkey dung which had the lowest value of ultimate tensile strength of 599 MPa.

When compared to conventional and organic quanchants, the control sample in the study's analysis of the mechanical characteristics of medium carbon steel quenched in animal dung media reveals a distinct possibility.

In this study has the highest ultimate tensile strength (1031 MPa) and hardness (381 HBN), which is in accordance with [12]. Who reported that ultimate tensile stress value is 1000 MPa and hardness of 380 HBN.

In contrast cow dung sample demonstrated (UTS 866 MPa, hardness 208 HBN) mechanical properties comparable to coconut water quenched sample steel studied by [13]. The results were reported to be (UTS 850

MPa, with hardness near 200 HBN). Both media through unconventional, provided sufficient cooling rates to enhance strength while maintaining moderate ductility. This comparism validates the potential of organic waste quanchants.

Similarly horse dung quenched steel (UTS 841 MPa, hardness 201 HBN) aligns closely with [14] whose established results of palm oil quenched steel produced UTS values of 840 MPa and hardness close to 200 HBN both quanchants yielded intermediate mechanical properties, balancing toughness and ductility. This suggest that organic quanchants with moderate cooling severity can achieve desirable mechanical property appropriate for engineering applications requiring both toughness and strength.

Table 2: Shows the Summary of Mechanical Properties of Medium Carbon Steel after cooling in Animal Dung

Sample	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Compressive Strength (MPa)	HBN	% Elongation
Control	931	1031	1104.17	381	5.40
Cow Dung	712	866	945.33	208	8.50
Donkey Dung	502	599	657.80	197	10.84
Horse Dung	780	841	866.32	201	8.08

Figure 3 shows that the measure of stress versus strains for control sample with the highest ultimate tensile stress of 1031 MPa and it strain at failure (5.4%) which is brittle.

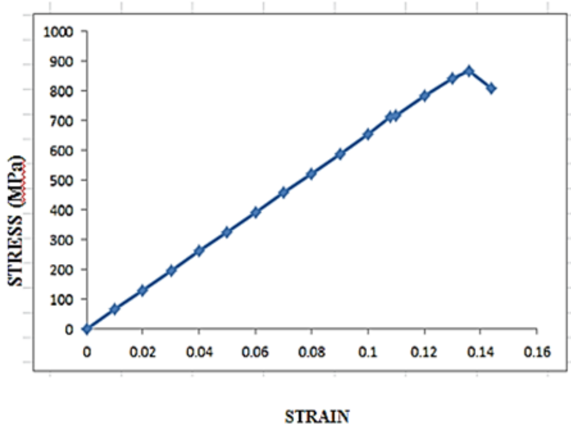

Figure 3: Stress-strain curve for control sample

Figure 4 shows the measure stress versus strain for sample cooled in cow dung media with ultimate tensile strength of 866 MPa and yield strength of 712 MPa. And it strains at failure (8.50%) which was found to be comparably ductile than control sample.

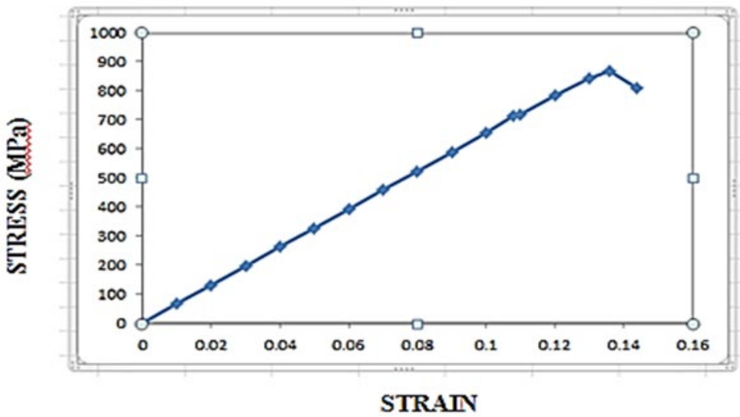

Figure 4: Stress – strain curve for sample cooled in cow dung medium

An elastic area with a yield strength of 502 MPa is depicted in Figure 5 and plastic region with ultimate tensile strength of (599 MPa) and strain at (10.84 %) which show an increase in ductility compare to all.

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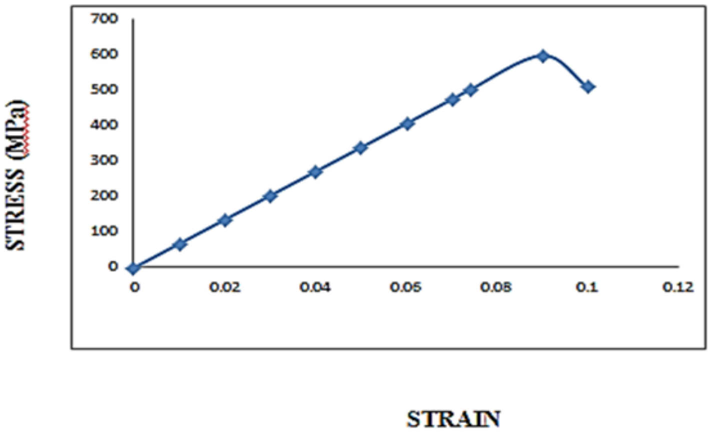

Figure 5: Stress-strain curve for sample cooled in donkey dung medium

Figure 6 shows region of yield strength of (780 MPa) and ultimate tensile strength of (841 MPa). It also shows a similar strain trend with sample cooled in cow dung medium

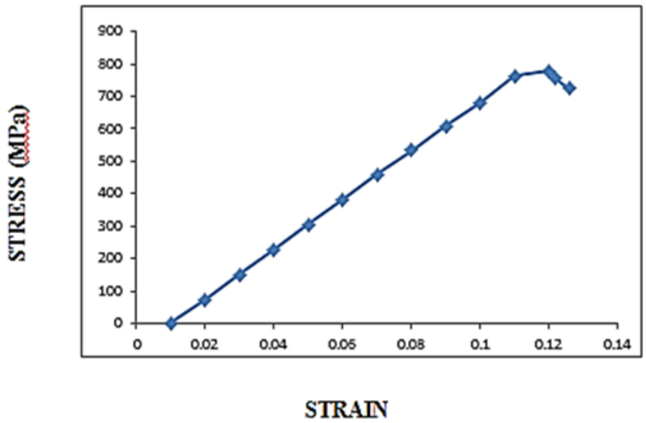

Figure 6: Stress-strain curve for sample cooled in horse dung medium

Table 3 shows that sample cooled in donkey dung have almost same mechanical properties with the standard medium carbon steel material for gear AISI when compared. Therefore, the material can be used for fabrication of gear. Also, material cooled in cow dung and horse compared favorably with a British Standard material (B.S) in term of ultimate tensile, strength hardness and percentage elongation. Therefore, the material can be used for drills, chisel and forging dies etc. The general influence of microstructural changes on mechanical properties is well documented in recent metallurgical research [15].

Table 3: Comparison between Material Properties of Experimental Sample and BS/A131 Standard Material [8, 9]

Sample	Chemical Composition (%)	Yield Strength (MPa)	Ultimate tensile strength (MPa)	HBN	% Elongation
Control	0.52c, 0.34Ni 0.75Mn, 1.53cr	931	1031	381	5.4
Cow dung		712	866	208	8.50
Donkey dung		502	599	197	10.84
Horse dung		780	841	201	8.08
B. S	0.50c, 0.80Mn				
Material for concrete	0.55c, 0.75Mn	570	925	250	12
drills, chiseli forging	0.60c, 0.65Mn	575	930	230	12
dies	0.65cr	620	850	250	15
AISI					
Gear material	0.48-0.50c				
	0.8MN, 1.65Ni	500	650	192	10
	0.7cr,				

3.1 The Microstructure

To evaluate this cooling activities: The prepared specimen from the cooled sample and the control sample underwent metallographic investigation and comparison. The analysis of metal microstructures using Scanning Electron Microscopy (SEM) (5000 X) and Energy-Dispersive X-ray Spectroscopy (EDS) remains a standard procedure in steel research [11, 12, 17]. The microstructure of control sample is shown in Figure 7a. It can be seen that the structure contains ferrite (white) with little grains of pearlite (black) and it contain some little blow holes. Similar phenomenon was reported by [17]

For sample cooled in cow dung medium which shows in Figure 7b. The micrograph of the sample cooled in cow dung demonstrates a low grain boundary with ferrite, pearlite, and low martensite in pearlite matrices, all of which enhance the sample's mechanical qualities. The existence of these phases confirms the quenching effect [10].

In the micrograph of donkey sample (Figure 7c) with a large grain structure contained pearlite mainly and ferrite structure which is responsible for high elongation property, see Figure c. While in Figure 7d shows a micrograph of sample cooled in horse dung media with large grain boundary and a structure of pearlite and little ferrite.

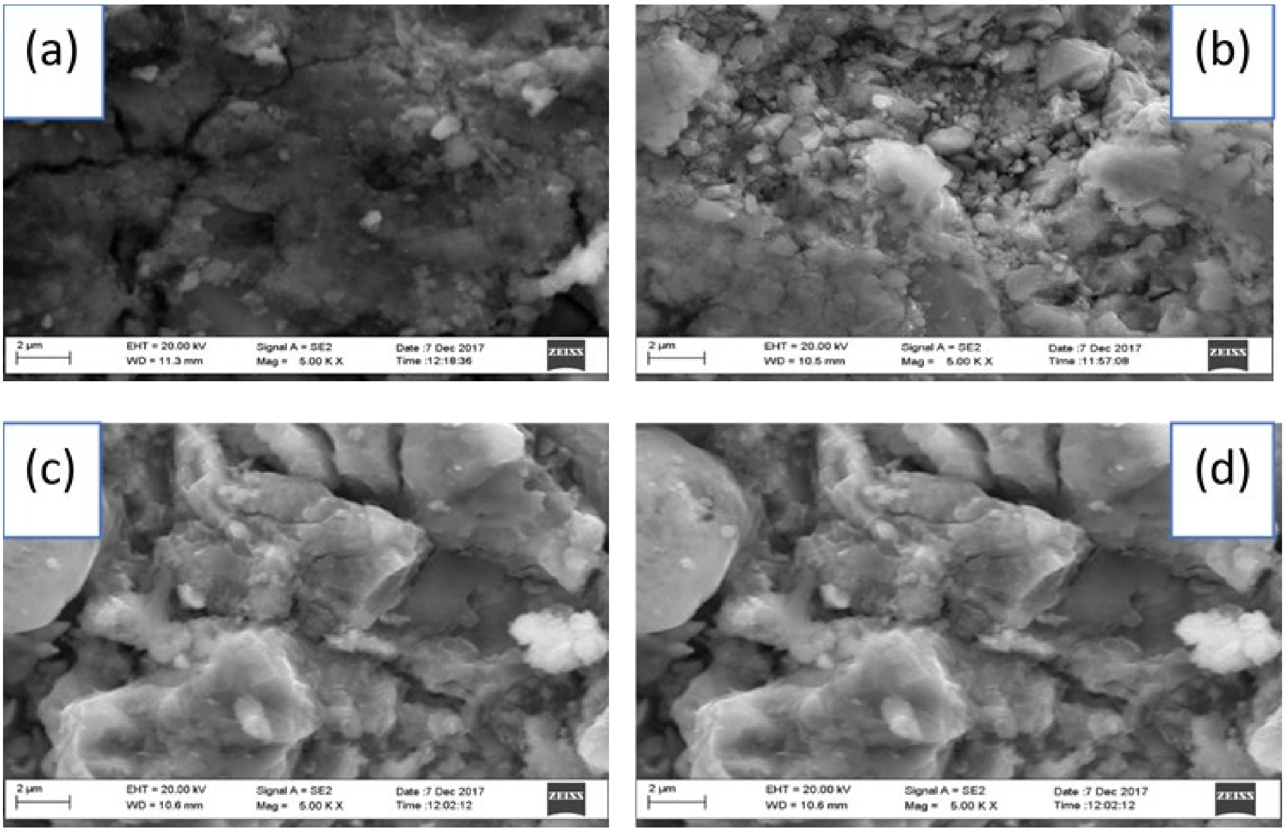

Figure 7: SEM images of (a) Control sample, (b) Cow dung (c) Donkey dung and (d) Horse dung treated samples (Magnification 5000X, 2 μm)

4.0 Conclusion

Using yield strength, tensile strength, compressive strength, hardness value, and percentage elongation, the efficiency of cow, donkey, and horse dung as cooling medium in this heat treatment of medium carbon steel has been statistically evaluated. The results obtained in these studies indicate that control sample is hard, tough and brittle. The cooling rate of donkey dung medium is less than that of cow and horse media. For high ductility and minimum toughness, cooling the medium carbon steel in donkey dung give satisfactory outcomes. The sample heat treated with cow dung was found to possesses good property in yield (712MPa), tensile strength (866MPa) and hardness value of (208HBN). Animal dung can be employed as a cooling or quenching medium for steel manufacture, which would assist prevent careless waste discharge into the environment and promote healthy living. Job opportunities could be created as a result of the processing and application of animal dung for steel heat treatment, which turns waste into wealth.

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