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Effect of Compaction on Thermal Conductivity of Aluminium Powder

Ogie Nosa Andrew[1], Oyejide Oluwayomi Joel[2*], Akusu Onomine Murray[3], Udumebraye Joseph Eruke[4]

[1,3,4] Department of Mechanical Engineering, Petroleum Training Institute, Effurun , Nigeria
[2] Department of Mechanical Engineering, Federal University of Petroleum Resources, Effurun, Nigeria

***Corresponding Author:** Oyejide Oluwayomi Joel, Department of Mechanical Engineering, Petroleum Training Institute, Effurun, Nigeria*

ABSTRACT

The use of aluminium alloys in engineering industries such as automotive structural application is rapidly growing. Aluminiun alloys are alternative engineering materials to steel. However, industrially, aluminium alloy powder is compacted via the process of powder metallurgy to produce a better material of good resistance and strength. In this research work, effect of compaction on thermal conductivity of aluminium powder was evaluated. The selected aluminum alloys has chemical composition of 98% Aluminium (Al), 0.2% Iron (Fe), and 0.1% Copper (Cu). Four specimens of aluminium powder were used and each specimen were compacted with different forces and sintered under the same temperature condition. The thermal conductivity of the different specimens was tested using electrical method. Results obtained were compared. It was observed that the higher the force of compaction, the higher the thermal conductivity. However, compaction has no effect on the thermal conductivity of the used aluminium powder sample. Furthermore, the higher the pressure, the higher the thermal conductivity of the compacted aluminium powder

Keywords: *Aluminium alloys, powder metallurgy, thermal conductivity, compaction, sintering, die*

INTRODUCTION

Aluminium alloy applications are numerous and this was as a result of its light weight, excellent weld ability, and corrosion resistance. The use of aluminium alloys in engineering industries such as in automotive, and structural application is rapidly growing. In terms of fatigue strength, aluminium alloys still offer lower fatigue strength than high strength steel [1-4]. Moreover, aluminium is an alternative to steel and in car production; it potentially increases the efficiency of the vehicles by providing a lower weight [5-6]. In industries, aluminium alloy powder can be compacted via the process of powder metallurgy to produce a better material of good resistance and strength [7].

Powder metallurgy is the process of blending fine powdered materials, pressing them into a desired shaped or form (compacting), and then heating the compressed material in a controlled atmosphere to band the material (sintering). It is also a material processing techniques in which particulate materials are consolidated to semi-finished and finished products [8]. Besides, the use of powder metal technology bypasses the need to manufacture the resulting products by metal removal process, thereby reducing costs. This process generally consists of four basic steps powder production, powder blending, compacting, and sintering. This technology is use in the manufacture of electronics components and in the automobile industry for the production of gears, sprocket, housing etc. Figure 1 shows uniaxial die compaction of metal powder.

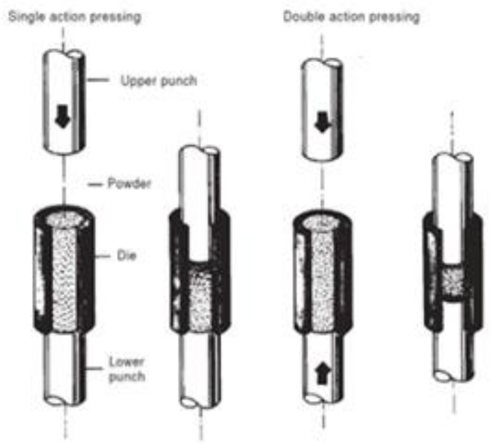

Figure1. *Uniaxial Die Compaction of Metal Powder [10]*

The next stage that follows powder compaction stage is called sintering. Sintering is basically heating the green compact to elevated temperatures for the purpose of creating inter-particle fusion through the thermally induced movement of atoms. Sintering, by nature is achieved at a temperature below the liquids of the material, and this ensure that the green compact retains the original shape. However, since diffusion rates increase with increasing temperature and are much higher within a liquid than a solid [11], it is desirable to sinter at the highest temperature possible and somehow incorporate the use of liquids.

MATERIALS AND METHOD

Materials

The following materials were used in this research work.

Aluminium Powder

In this research work, aluminium alloy with the chemical composition of 98% Aluminium (Al), 0.2% Iron (Fe), and 0.1% Copper (Cu) [Figure 2] was used.

Figure2. *Aluminium Powder (20 micron)*

Mild Steel Rod

Mild steel is an alloy which contain low amount of carbon ranges from 0.05% – 0.25%. Its choice was generally based on cost and workability. It was used for the construction of hollow cylindrical dies and punches (Figure 3).

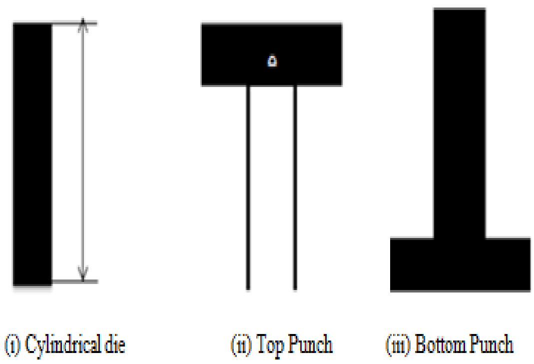

Figure3. *Mild Steel Rods*

The other materials used in this research work include; stopwatch, calorimeter, thermometer, multi-meter, and heating element.

Compaction Procedure

The inside wall of the constructed die material was properly lubricated to enhance easy ejection of the green compact. The aluminium powder was gently poured into the die where compaction was allowed to take place with an initial force of 10KN (Figure 4). Finally the green compact (i.e., end product) was ejected from the die as presented in Figure 4.

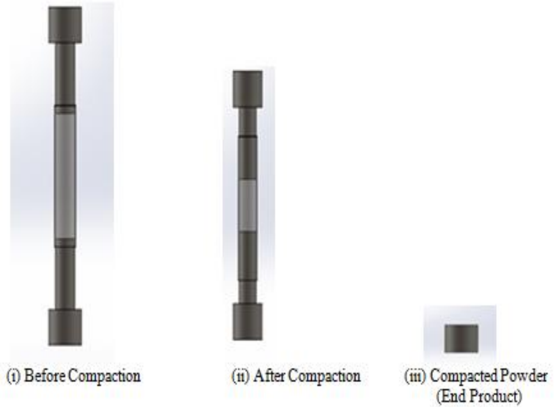

Figure4. *Compaction Procedure*

The compaction process was repeatedly done using forces of 12KN, 20KN, 30KN, and 40KN, were it was subjected to a sintering temperature of 450^{0}C for duration of one hour.

Thermal Conductivity Test Procedure

A known volume of water was poured inside the calorimeter. The specimen was connected to the heating element which in turn was connected to power source and other necessary connections were made. The specimen and heating element were inserted inside the calorimeter with the bottom of specimen making contact with the water. Current readings and voltage readings were measured and recorded. Figure 5 shows the experimental setup.

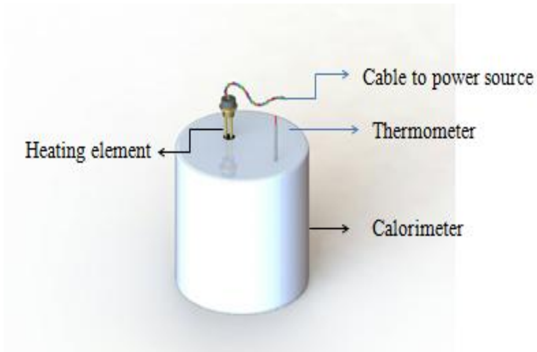

Figure5. *Experimental Setup*

RESULTS AND DISCUSSION

The voltage, current, and resistance readings are obtained as;

Voltage (V) = 235V

Current (I) = 4.72A

Resistance (R) = 807 Ω

Specimen 1 =12KN

Specimen 2 = 20KN

Specimen 3 = 30KN

Specimen 4 = 40KN

Table 1 shows the results obtained from the research work

Table1. *Results obtained with four different Specimens*

S/N	Time (minutes)	Temperature (^{0}C)			
		Specimen 1	Specimen 2	Specimen 3	Specimen 4
1	0	28	28	28	28
2	4	28.5	30	30.5	31.5
3	8	30	33	34	35
4	12	33	36	38	40
5	16	37.5	40	43	45
6	20	41	44	50	53
7	24	44.5	47	54	59
8	28	46	49	57	61
9	32	47	51	59	64

The results obtained show an increased in the time of power supplied to the heating element lead to corresponding increase of temperature (Figure (6) and Figure 7). This phenomenon occurs with the four different samples used. Furthermore, specimen 4 with compaction force of 40N has the highest temperature. Specimen 1 with least compaction force has the least overall temperature at a time of 32 minutes. Thus, the higher the compaction force, the higher the temperature required for sintering.

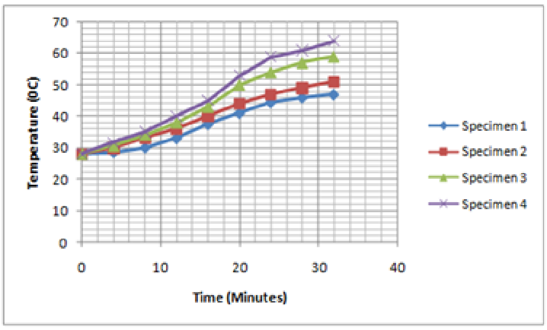

Figure6. *Plot of Temperature against Time*

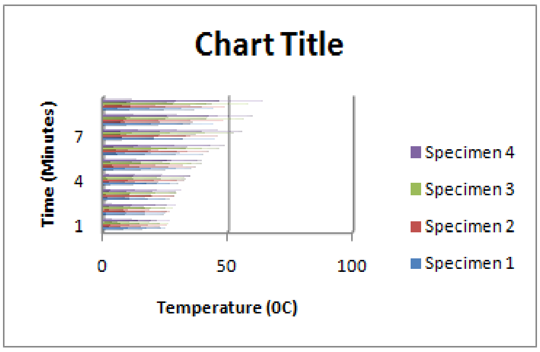

Figure7. *Bar Chart showing plot of Temperature against Time*

The power required was calculated from equation (1)

$$P = IV \quad (1)$$

Where,

P = Power Supplied

V= Voltage

I = Current

But,

$$V = IR \quad (2)$$

Equation (1) becomes;

$$P = I^2R \quad (3)$$

Power loss is equal heat (Q) gained or conducted by the body,

Thus,

$$Q = I^2R \quad (4)$$

The heat gained by the body was obtained as 58.83W. The thermal conductivity of the specimen was calculated from equation (5)

$$k = \frac{Qdx}{Adt} \quad (5)$$

Where,

k= Thermal conductivity

Q = Heat gained by the body

dx = distance in the direction of heat flow

A = Area of cylindrical surface in contact with heating element

dt = Difference in temperature of heating element and cooling water

The following assumptions were made when carrying out thermal conductivity test.

- Negligible heat loss to the surrounding
- One dimensional heat flow
- Uniform supply of power

However, the area of the cylindrical surface is given by Equation (6)

$A=2\pi\ r(r+h)$

Where

r= Radius of cylinder in contact with heating element.

h= Height of cylinder in contact with heating element.

The area of cylindrical surface in contact with

heating element was obtained as $0.000165m^2$

Table 2 shows the results obtained with compaction force and thermal conductivity in the cooling substance (water).

Table2. *Results of Thermal Conductivity*

Specimen	Compaction Force (N)	Thermal Conductivity (W/m^0C)
1	12	22.8
2	20	23.1
3	30	23.7
4	40	24.1

From Table 2 and Figure 8, the extent at which heat was transfer through the specimen was a function of their individual thermal conductivity. Moreover, the higher the compaction forces, the higher the thermal conductivity. Since, pressure is directly proportional to compaction force, increased in thermal conductivity will results to increase in temperature.

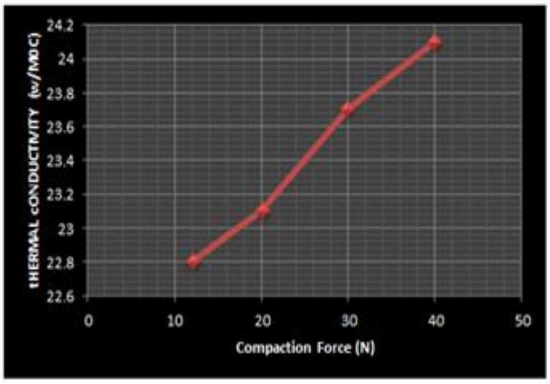

Figure8. *Plot of Thermal Conductivity against Compaction Force*

CONCLUSION

The outcome of the results obtained from this research work entitled, effect of compaction on thermal conductivity of aluminium powder reveal that the specimen with the highest compaction force of 40KN force has the highest thermal conductivity ($24.1W/m^0C$) compare to other specimens. For the specimen with compaction force of 30KN, conductivity value of 23.7KN was achieve, and this was greater than both specimens compacted with 20KN and 12KN forces respectively. It was observed that the higher the compaction force, the higher the thermal conductivity.

RECOMMENDATION

Since the difference in thermal conductivity of the tested compacted aluminium powder was not much as a result of the range of forces used, it is recommended that any person embarking on similar project should use forces whose difference in magnitude is significant, e.g. 10KN, 80KN, 150KN, 250KN. This will give a better comparison.

Also, the same force should be used to compact at least four different samples but under the same sintered temperature condition. With this, Moreover, the duration of sintering affects thermal conductivity. Thus, sintered time interval should be increase, and the die diameter and height should be increase also, as this will enable more time of heat transfer through the specimen thereby preventing same heat flow at the same time interval.

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