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Productization, Characterisation and Analysis of RX 100 motorcycle piston from End of Life Aluminium pistons

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Abstract
Recycled Aluminium are top choice engineering materials due to their affordability and low-cost. The objective of this study is to design and develop an RX 100 motorcycle piston, characterise the piston material and conduct a thermo-mechanical analysis of the piston developed. The Piston investigated in this study was developed from end-of-life (EOL) recycled automobile Aluminium pistons. The piston materials were characterised using XRF and SEM-EDS to ascertain the elemental composition and morphology of the piston. A model of the piston was designed using SolidWorks, and the complete design imported in Ansys workbench for static analysis of piston. The main parameters considered in the analysis are the operating gas pressure and temperature of the piston. Results obtained in the study indicated that the end-of-life automobile Aluminium pistons performed excellently under static analyses.

Keywords: Aluminium, piston, recycling, SEM-EDS, static analysis

1. Introduction

A piston is a sliding plug (cylindrical metal component) that fits tightly inside the bore of a cylinder which reciprocates in the cylinder under gas pressure and converts thermal energy into mechanical energy in an internal combustion engine. The primary purpose of pistons is to transfer force from expanding gas in the cylinder to the crankshaft through the piston rod. The piston also acts as a moveable end of the combustion chamber. The cylinder head is the stationary end of the combustion chamber (“05_chapter1 | Piston | Heat Treating,” n.d.).

1.1 Parts of a Piston

The Piston has two significant parts, which are as follows:

- Piston Crown
- Piston Skirt

Figure 1 below shows the parts of the Piston

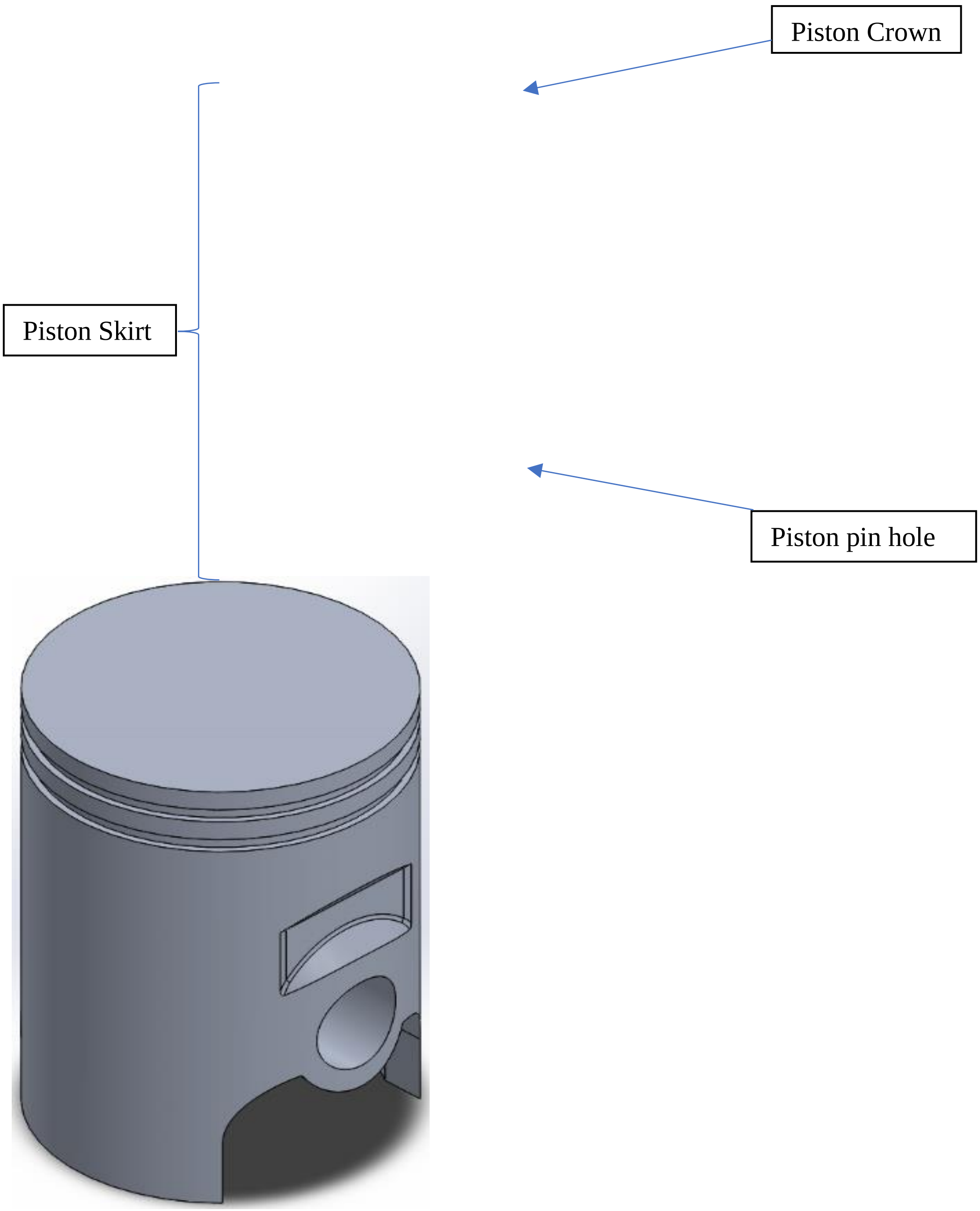


Figure 1. Parts of a Piston

1.1.1 Piston Crown

The top of the piston is called Head or Crown. It is the top surface (closest to the cylinder head) of the piston which is subjected to pressure fluctuation, thermal stresses and mechanical load during regular engine operation. Towards the top of the piston of a few grooves are cut to house the piston rings. The bands left between the grooves are often called lands. These lands support the rings against the gas pressure in the radial path.

1.1.2 Piston Skirt

The part of the piston beneath the rings is referred to as Skirt. Its absorbs thrust due to gas strain and helps retain lubrication.

Aluminium alloys are preferred materials for pistons both in gasoline and diesel engines due to the following characteristics: low density, high thermal conductivity, simple netshape fabrication techniques (such as casting and forging), easy machinability, high reliability and excellent recycling characteristics(Rufeena & Saaminathan, 2017).

Several commercial Finite Element software has been employed in the stress analysis of Internal Combustion Engine pistons. The PISDYN (Jian, Zhong-yu, Shi-ying, Sheng-wei, & Li-jun, 2019; Saade & Queenan, 2010); ANSYS (Buyukkaya & Cerit, 2007; Jog, Anthony, Bhoinkar, Kadam, & Patil, 2020; Mastan & Reddy, 2016; Reddy, Sudheer, & Kumar, 2007; Rufeena & Saaminathan, 2017; Sathish Kumar, 2016; Wang, Liu, & Shi, 2010; Yadav & Mishra, 2015) and COSMOS works have been used in the analysis (Golbakhshi, Namjoo, Dowlati, & Khoshnam, 2016; Mastan & Reddy, 2016).

2. Materials and Methods

The materials used to develop the motorcycle pistons were aluminium alloy piston scraps of generators, motorcycles, vehicles and trucks. These materials were obtained locally from the scrap market and a roadside mechanic workshop, both at Ughelli in Ughelli North LGA of Delta State of Nigeria.

2.1 Recycling of the End-of-Life Aluminum scraps

Aluminium can endlessly be renewed and reused after their end of useful life. The aluminium scraps were cleaned, sorted into different metal streams and later compressed into bales. This process is necessary to ensure that the aluminium collected is separated from other metals. The sorted aluminium was washed using water and 0.1M NaOH. The aluminium was allowed to dry for 24 hours. The dried aluminium scraps were subjected to the temperature up to 7000℃ in the furnace. The furnace used for the project is an Electrically controlled gas-fired Crucible furnace. The propane gas (C_3H_8) is used to fire the furnace. During the process of melting, the impurities present in the aluminium will float to the top surface of the hot aluminium in the form of a layer called dross. The dross is removed using a specialised scraping tool.

2.2 The development of RX 100 motorcycle piston

The motorcycle piston was developed by pouring the molten aluminium in a permanent mould formed from AISI 1018 mild steel. The permanent mould was designed to have a shrinkage allowance of 1.5%. Tables 1 and 2 shows the mechanical and chemical properties of the AISI 1018 mild steel used in the formation of the permanent mould. Figure 2 shows the permanent mould developed from the AISI 1018 steel. The Cast piston was machined to a finish on a lathe machine. Figure 3 shows the finished aluminium piston developed. Table 3 is the geometric values of the aluminium piston developed.

Table 1. The mechanical property of AISI 1018 Steel ("AISI 1018 Mild/Low Carbon Steel," n.d.)

Property	*Value*	*Units*
Density	7870	kg/m^3
Modulus of Elasticity	205	GPa
Ultimate Tensile strength	440	MPa
Poisson Ratio	0.290	N/A
Yield strength	370	MPa

Table 2. The chemical property of AISI 1018 Steel ("AISI 1018 Mild/Low Carbon Steel," n.d.)

Element	*Symbol*	*Content (%)*
Carbon	C	0.14 - 0.2
Manganese	Mn	0.60-0.90
Iron	Fe	98.81 - 99.26 (as remainder)
Phosphorus	P	≤0.040
Sulfur	S	≤0.050

Figure 2. The permanent mould developed from AISI 1018 steel

(a) Unmachined piston

(b) Machined piston

Figure 3. The final aluminium piston developed

Table 3. The Geometric values of the piston

Dimensions	***Size (mm)***
The diameter of the Piston crown (D)	50
The thickness of the Piston Head (t_H)	5
The radial thickness of Ring (t_1)	1
Axial thickness of the piston ring (h)	2
Width of ring land (h_2)	1
The thickness of the piston barrel at the open end (t_2)	2
Length of the skirt (l_s)	69
Piston pin diameter (d_0)	14

The engine and transmission specifications for the Yamaha RX 100 petrol engine whose piston was developed is shown in Table 4

Table 4. Engine and Transmission specification for Yamaha RX 100 ("Yamaha RX 100," n.d.; "Yamaha RX 100 Specifications, Features, Mileage, Weight, Tyre Size," n.d.)

Parameters	**Values**
Engine type	Two-stroke petrol engine
Number of cylinders	Single cylinder
Bore	50 mm
Stroke	2
Power	11 HP (8.206 kW) @ 8500 RPM
Torque	10.39 Nm @6500 RPM
Top speed	120kmph
Fuel capacity	10.5L
Fuel consumption	30-35 km/L
Oil capacity	0.650 L

2.3 Microstructural characterisation

The recycled aluminium piston material was characterised using X-ray fluorescence (XRF) for the elemental composition of the aluminium material and Scanning Electron Microscopy Energy Dispersive Spectroscopy (SEM-EDS) for the change in material composition across the surface at a specific point. The morphologies and elemental composition of the aluminium samples were characterised using a Hitachi SU70 Field Emission Scanning Electron Microscope (FESEM, Hitachi, Japan) at 20 keV coupled with an Oxford energy dispersive spectrometer (EDS, Oxford Instruments, Concord, MA).

2.4 *Static analysis of the piston*

The geometry of the aluminium piston was obtained from solid works and imported in ANSYS R18.1 for thermomechanical analysis of the piston, as shown in Figure 4. The CAD model was discretised into 35573 nodes and 20441 triangular elements, as shown in Figure 5. The boundary conditions were applied to the discretised model, followed by processing and postprocessing. Table 5 shows the analysis of the mesh model generated in ANSYS. The aluminium A4032 mechanical properties were used to predict the behaviour of the aluminium piston during the simulation. Table 6 shows the mechanical properties of the A4032 aluminium alloy.

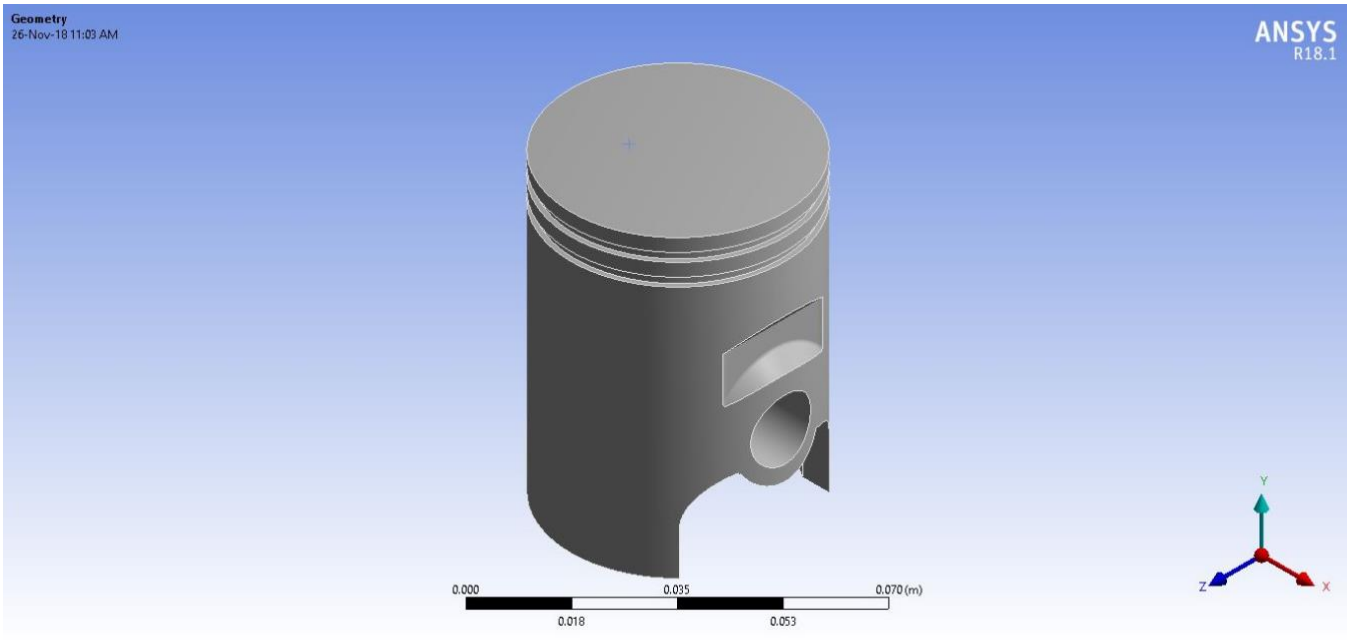


Figure 4. CAD geometry of the aluminium piston

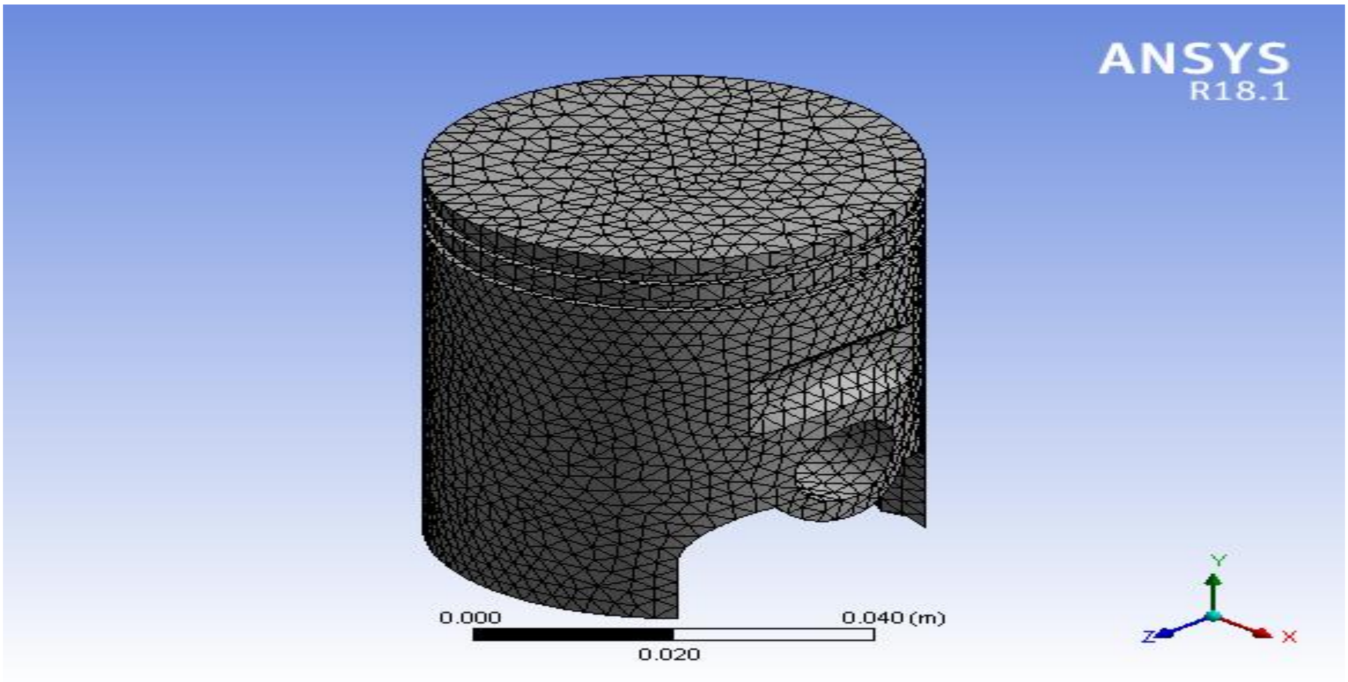


Figure 5. Discretised aluminium piston with 35573 nodes and 20441 elements

Table 5. Analysis of the mesh model of the Piston as generated.

Statistics	
Nodes	35573
Elements	20441
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Defeature Size	Default
Minimum Edge Length	6.9813e-004 m
Quality	
Error Limits	Standard Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	Element Quality
Min	0.2291
Max	1.
Average	0.81049
Standard Deviation	0.11459
Inflation	
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2

Table 6. Mechanical properties of A4032 aluminium alloy

Parameters	Value
Density, (kg/m^3)	2684.95
Poisson's ratio	0.33
Coefficient of thermal expansion, (1/K)	79.2×10^{-6}
Elastic modulus, (GPa)	79
Yield strength, (MPa)	315
Ultimate tensile strength, (MPa)	380
Thermal conductivity, ($W/m/^0C$)	154

3. Results and Discussion

3.1 *Microstructure Characterisation*

Table 7 shows the XRF result obtained for the recycled aluminium piston material. The XRF show the presence of Aluminium, alloying compounds and impurities at percentage concentrations. Aluminium concentration was found to be 95.5%; this indicates that the piston material is predominantly aluminium. The presence of iron, copper and manganese are beneficial to the aluminium as it provides substantial increases in strength and facilitates precipitation hardening of the piston material. The presence of copper to aluminium can also reduce ductility and corrosion resistance. Iron as the most common impurity in aluminium is the leading cause of porosity in the cast material; this could be as a result of the formation of the β-phase iron-containing intermetallics. However, the presence of transition metals, Mn and Cr can stabilise the formation of the iron-containing intermetallics. SEM micrograph of the aluminium material is as shown in Figure 6.

Table 7. XRF of the recycled Aluminium for the piston

Compound	Al	Ti	V	Cr	Mn	Fe	Ni
Concentrated Unit	95.5%	0.03%	0.002%	0.093%	0.15%	1.06%	0.820%
Compound	Cu	Sb	Ba	Ce	Eu	Os	Pb
Concentrated Unit	1.436%	0.28%	0.17%	0.05%	0.36%	0.058%	0.012%

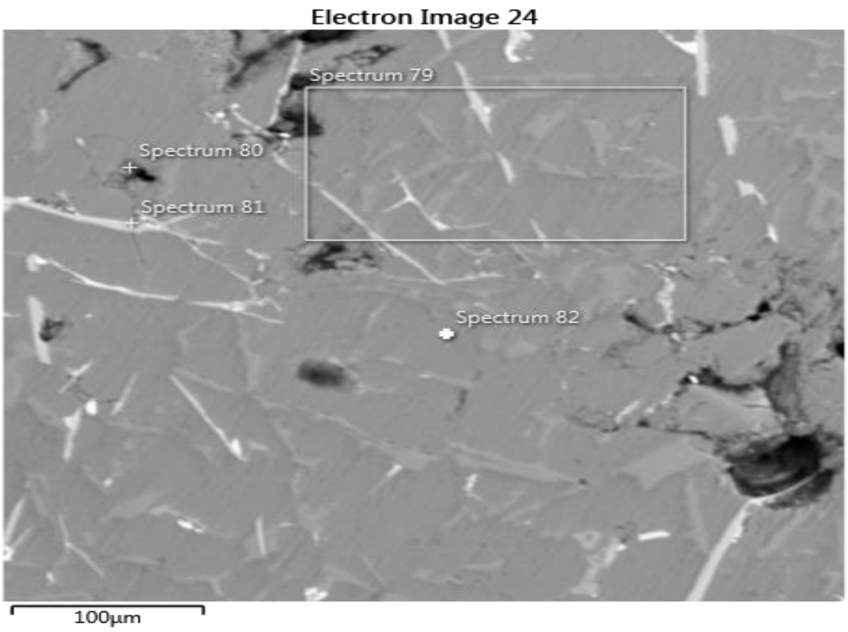


Figure 6. SEM-EDS micrograph of Aluminum displaying points of interest

Table 8. Summary of the EDS Analysis of the Aluminium

Element	**Weight, %**			
	Spectrum 79	***Spectrum 80***	***Spectrum 81***	***Spectrum 82***
Al	69.2	79	55	91
Si	20	12	9.4	1.2
C	6.5	4.6	7.1	5.3
O	4.3	4.4	4.2	2.5
Fe	-	-	19.7	-
Cu	-	-	4.5	-

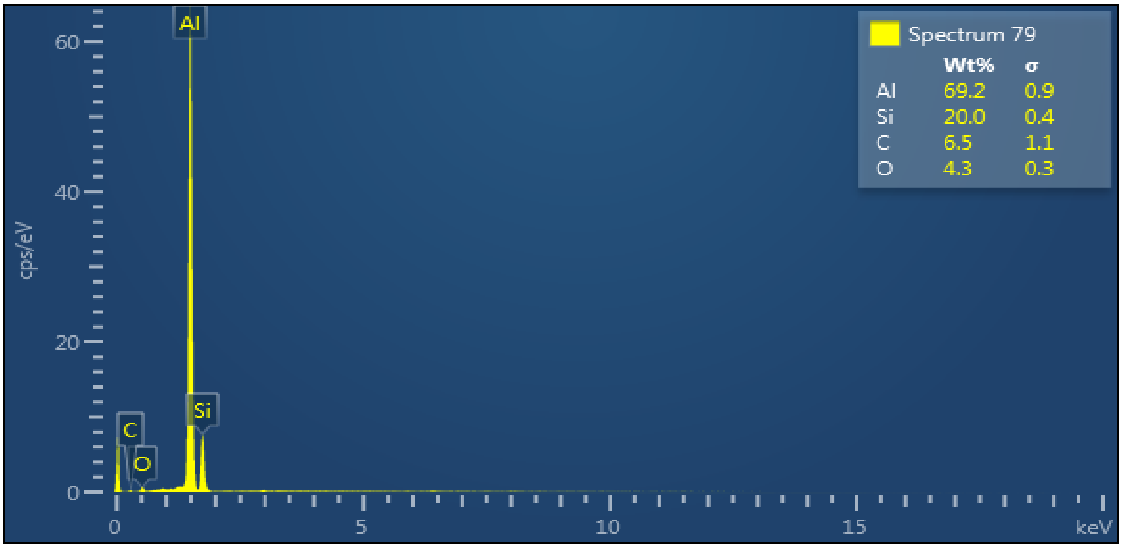


Figure 7. EDS Spectrum of point 79

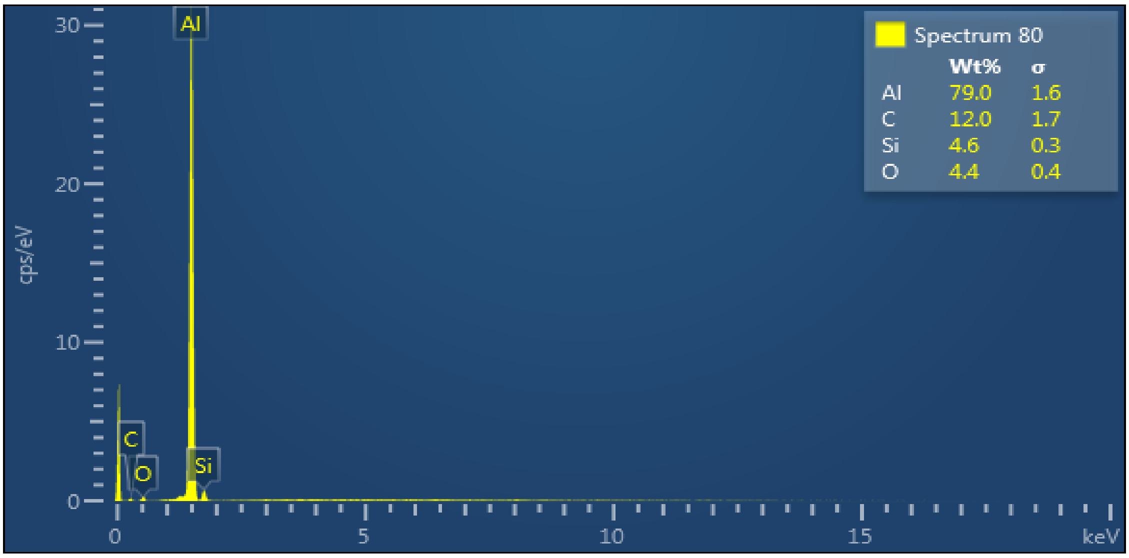
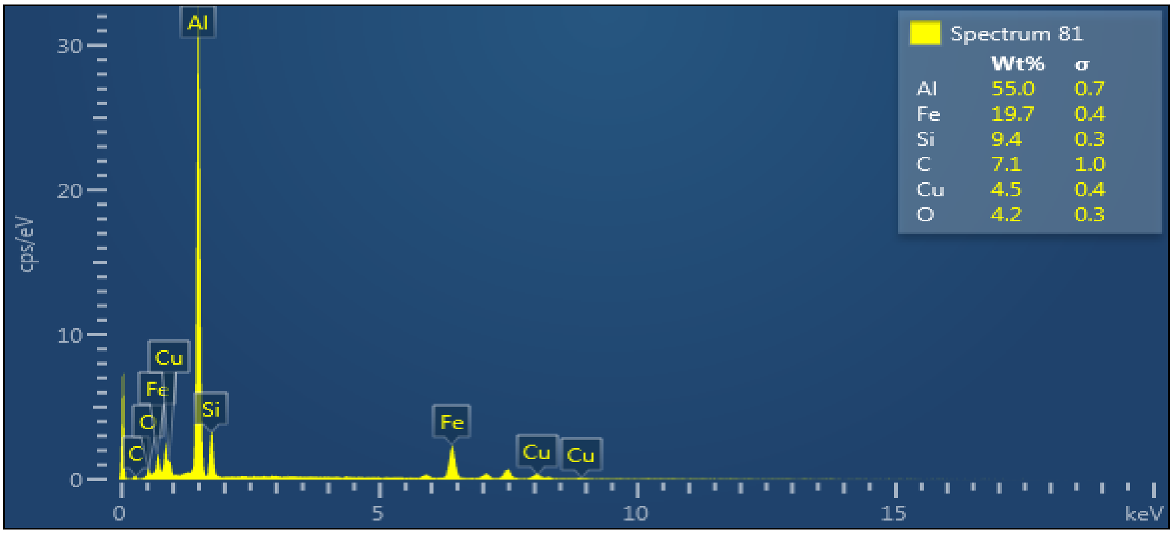


Figure 8. EDS Spectrum of point 80



`**Figure 9. EDS Spectrum of point 81**

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Figure 10. EDS Spectrum of point 82

Figure 6 shows the SEM micrograph of Aluminium sample. Points 79-82 on the spectrum are the points of interest analysed for the sample, as shown in Figures 7-10 and summarised in table 8. The presence of C and O indicates the existence of adventitious carbon and oxygen on the surface of the aluminium ("X-ray Photoelectron Spectroscopy (XPS) Reference Pages: What is Adventitious Carbon?" n.d.) in all the spectrum. The EDS spectrum indicates that the material is mainly an aluminium with alloying elements and few impurities.

3.2 Static Analysis

The static analysis for the aluminium piston was conducted using the ANSYS software. The piston was subjected to a load of 5MPa. The von Mises stress and total deformation of the piston under thermal loading were evaluated.

3.2.1 Von Mises Stress on the Piston

The Von-Mises stress is used to predict yielding of materials under any loading condition. The yield strength of Aluminium was obtained as 315 MPa. The von Mises stress distribution obtained for the piston in this analysis, as shown in figure 11 is 101.08 MPa. This value is below the yield strength of the aluminium alloy used in the analysis.

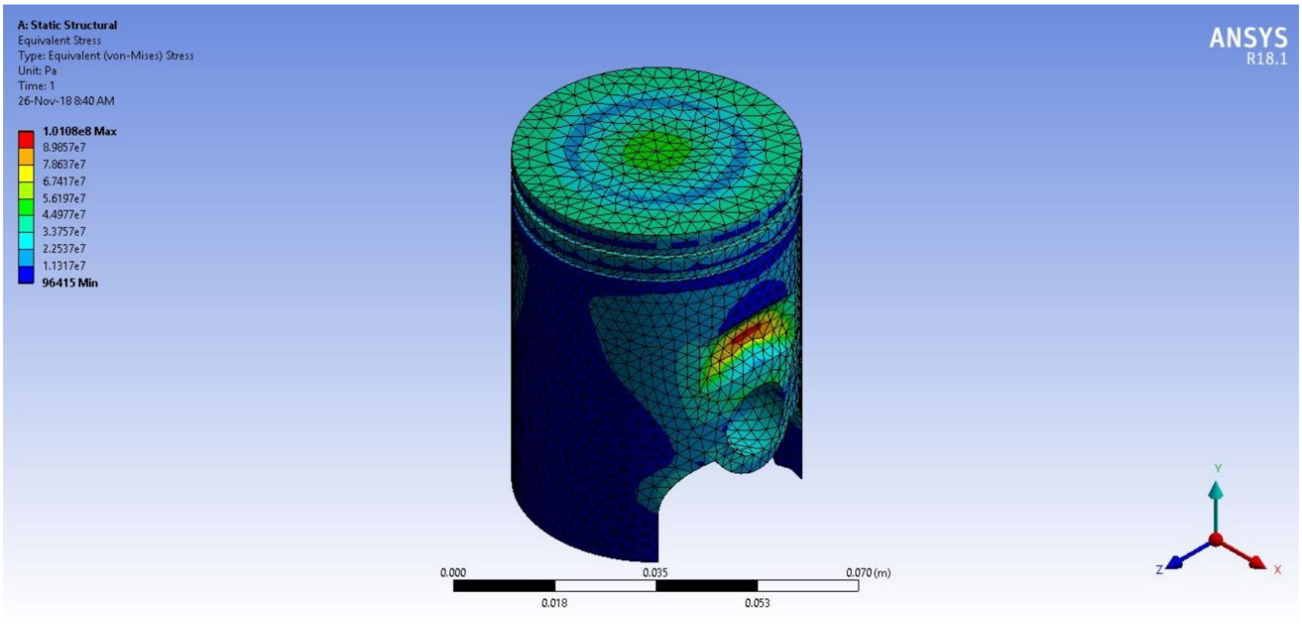

Figure 11. von Mises stress distribution

3.2.2 Total Deformation of the Piston

The maximum deformation of 4.9607×10^{-5} m occur at the centre of the piston crown, and the minimum deformation of 2.8651×10^{-11} m occur at the gudgeon pin hole region respectively as shown in fig. 12.

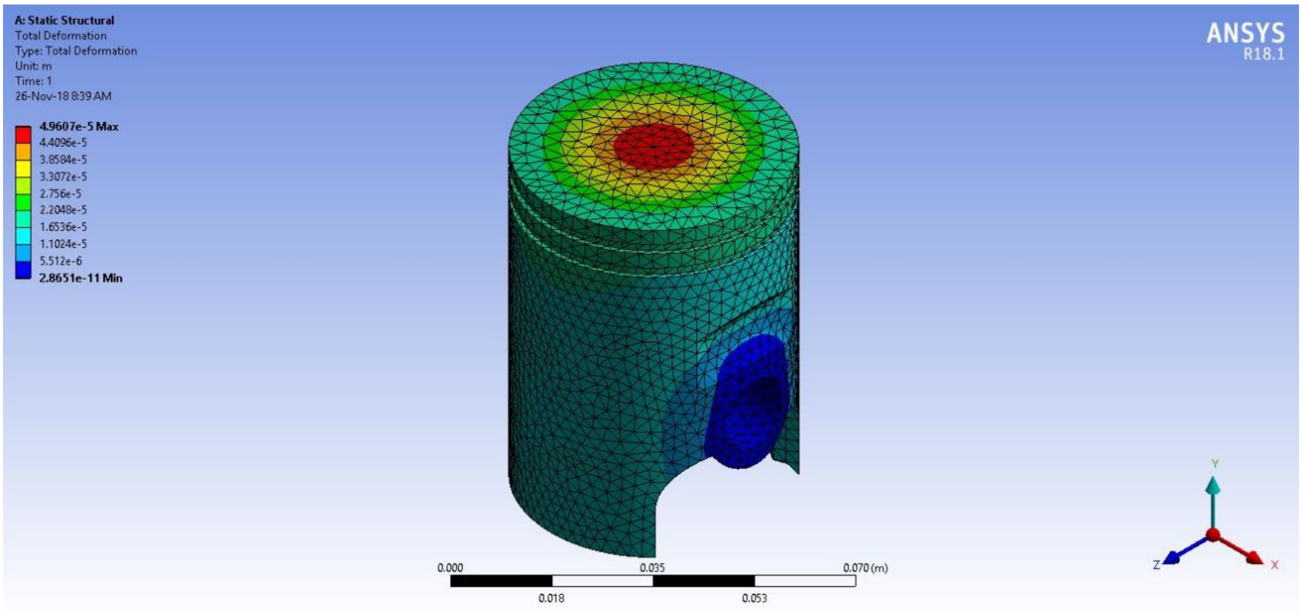

Figure 12. The total deformation of the piston

Conclusion

In this study, end of life aluminium pistons was recycled, characterised and used to develop the RX 100 motorcycle piston. The piston developed was subjected to static analysis on ANSYS. The following are a summary of the findings:

i. The recycled End of life aluminium piston materials was found to contain a high percentage of Aluminium, some alloying compounds and few impurities as shown from the XRF results obtained as shown in Table 7.

ii. The presence of iron in the recycled aluminium and the casting process are responsible for the porosity in the cast metal.

iii. XRF gave the general elemental composition of the aluminium alloy while the EDS revealed the spot to spot surface composition on the material.

iv. The AISI 1018 steel used for the permanent mould was able to withstand the high molten temperature of the aluminium alloy without any physical damage on the mould.

v. The static analysis conducted for the developed piston using ANSYS gave good approximations of the von Mises stress and total deformation of the piston.

vi. The results obtained for the von Mises stress indicates that the yield strength is higher than the obtained von Mises stress. The result shows that the material will not fail due to yielding during service.

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