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Fabrication and Assessment of a Motorcycle Piston using the Traditional Sand Casting Method

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Abstract**:** The RX 100 motorcycle piston was fabricated from end-of-life automobile piston using the traditional sand casting method. The fabricated piston was subjected to thermal analysis using ANSYS R18.1 version software to ascertain its performance under thermal loads. The recycled EOL aluminium used in the fabrication of the piston was characterised using SEM-EDS to determine the composition and morphology of the material. Results obtained show that the EOL aluminium employed in the fabrication of the piston performed excellently under thermal loads, and the SEM-EDS indicates that the material is predominantly aluminium with beneficial alloying elements.

Keywords**:** Aluminium, piston, recycling, sand casting, SEM-EDS, static analysis.

1. Introduction

A piston is a cylindrical engine component that moves smoothly along the surface of the cylinder bore while maintaining continuous contact with it during the combustion process. It is an essential component of the reciprocating engine. The piston is the loose end of the combustion chamber while the stationary end of the combustion chamber is the cylinder head[1], [2].

In an Internal Combustion Engine (ICE), the piston converts the thermal energy of fuel into mechanical energy. The primary functions of the piston are: (a) To transmit the gas forces through the connecting rod to the crankshaft. (b) To seal gas leakages of the crankcase and prevent the infiltration of oil from the crankcase into the combustion chamber together with the piston rings and combustion chamber. (c) To dissipate absorbed combustion heat to the cylinder liner and cooling oil [3], [4]. The primary forces acting on a piston are (a) Forces due to the explosion of fuel gas (b) Forces due to compression of fuel gas (c) Thermal load (d) inertia force due to the high frequency of reciprocation of the piston (e) Friction and forces at the crank pinhole.

Aluminium (Al) and its alloys are excellent materials of interest because of their increasingly significant role in applications requiring lightweight. Aluminium is a durable structural material that is resistant to chemical attack and degradation [5-7]. The cast aluminium alloys are choice materials in most automobile pistons. The cast aluminium alloy is responsible for excellent and lightweight thermal conductivity. Pistons are designed to withstand high combustion temperatures[8]. Casting refers to the pouring of molten metal of required composition into a mould having the desired cavity [9]. The cast metal is allowed to cool and solidify to take the desired shape of the cavity.

There are several methods used in the casting of aluminium alloys. The centrifugal casting process [9], [10]; direct metal casting on a permanent metallic mould [8], [11], [12]; squeeze casting or liquid metal infiltration [13]–[19]; stir casting [20-21].

The metal casting process takes the following steps, as outlined in Figure 1.

Figure 1. The metal casting process

In this study, the traditional sand-casting method was employed to fabricate aluminium alloys for the development of motorcycle piston. The fabricated aluminium was characterised using SEM-EDS to ascertain the morphology and elemental composition of the aluminium alloy.

2. Materials and Methods

The materials used are bentonite, gelatinised starch, water and aluminium alloy piston scraps from generators, motorcycles, vehicles and trucks obtained locally from the scrap market and selected mechanic garages at Ughelli Town, in Delta State, Nigeria. The traditional sand-casting technique was used in the fabrication of the aluminium alloy pistons. The steps involved in the traditional sand casting is shown in Figure 2.

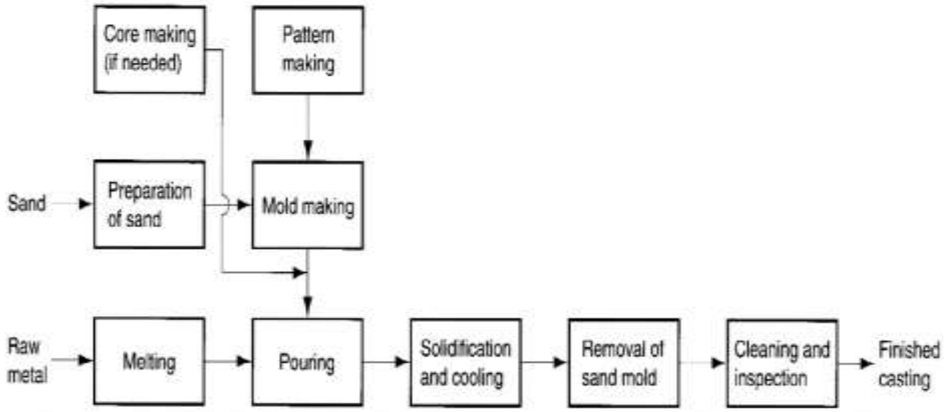

Figure 2. Steps involved in the traditional Sand Casting

2.1 Traditional sand-casting technique

2.1.1 Pattern and core making

The Pattern and Core box used in developing this piston were produced from a polymeric material. Figure 3a-3d shows the pictures of the Pattern and Core box. The bentonite, which is the base material used as the core sand in this study, was mashed to an excellent particle size with the aid of a pestle on a flat surface. Starch, water, and bentonite were thoroughly hand mixed to form the core sand. Utmost care was taken to ensure that stones and other impurities were removed from the sand during this operation. The prepared core sand was loaded into the two halves of the resin core box, as shown in Figure 4. The two halves loaded with the core sand was after that carefully joined together and held for an hour under the intense heat from the sun, as shown in Figure 5. The two halves of the split core box loaded with the clay were dismantled to obtain the core, as shown in Figure 6. The core formed was sun-dried for two weeks.

Fig 3a). The pattern

Fig 3b). The Split pattern

Fig 3c). The core box

Fig 3d). The assembled core box

Figure 4. Core box loaded with clay

Figure 5. Assembled core loaded with clay

Figure 6. The processed core

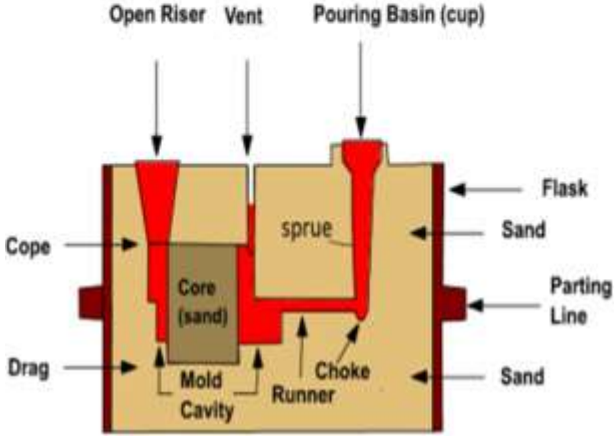

Figure 7. A typical sand mould

2.1.2 Moulding, melting and pouring process

The process involves sieving the green moulding sand to remove dirt and impurities. The dimensions of the moulding flask were carefully traced on a flat wooden surface to obtain the mid-point. The moulding flask was placed on the traced outline, and one half of the split pattern was placed at the centre of the moulding which preceded the sprinkling of parting powder on the surface of the pattern. The prepared mould was then gradually used to fill up the flask. The overfilled sand was rammed with a pestle and levelled with a metal bar. These steps were repeated for the cope and drag.

The pattern was removed to form the cavity for the casting. For the melting operation, the aluminium scraps were washed and dried thoroughly. The aluminium piston scraps were sent to the furnace for melting. As the piston melts, more piston scraps are fed into the furnace to obtain more volume. The electrically controlled, propane gas-fired crucible furnace was allowed to run for about three minutes to reach the pouring temperature of 650℃ –700℃. Before pouring, the mould flask (i.e. the cope and drag assembly) was adequately arranged at the mouth of the furnace while the furnace was automatically tilted to release the molten metal into the mould through the in-gate system.

A ladle was also used to channel the molten aluminium alloy into the moulds properly. Molten metal spotted rising in the riser, showed that the molten had filled the required cavity. A typical sand mould is represented schematically in Figure 7. Figures 8a-h is the pictorial depiction of the moulding,

Figure 8a. Mould preparation

Figure 8b. Application of parting powder on mould

Figure 8c. Sprue Pins placed on the mould

Figure 8d. Ramming of the mould

Figure 8e. Cope and Drag

Figure 8f. Core added to the moulding flask

Figure 8g. Cope and Drag ready for pouring

Figure 8h. The pouring of molten metal

2.1.3 Solidification, removal and cleaning process

The sand mould was carefully dismantled to obtain the cast piston which was machined to an excellent finish using the lathe machine. Figure 9 shows the cast aluminium motorcycle piston. Table 1 shows the geometric values of the piston fabricated.

The engine specification used is a two-stroke single-cylinder type Yamaha RX 100 petrol engine with parameters listed in table 2. Table 3 indicates the mechanical properties of A4032 aluminium alloy, which is used for the simulation of the developed piston material.

Table 1. Geometric values of the motorcycle piston fabricated

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_o)	*14*

Table 2. Engine and Transmission specification for Yamaha RX 100

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*

Table 3. 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/^{0}C]	*154*

Figure 9. Cast Piston

2.2 Microstructural analysis of the recycled aluminium alloy

The surface morphology and elemental composition of the recycled EOL aluminium alloy were studied using SEM with associated elemental analysis by EDS. Both SEM and EDS characterisations were carried out using the Phenom Pro X system (Phenom-World, Eindhoven, The Netherlands) equipped with a 4-segment backscattered electron detector (BSD), a silicon drift detector for EDX analysis, and Phenom Pro Suite software.

2.3 Thermal analysis of the aluminium piston

The ANSYS R18.1 version software was used to create the geometry of the aluminium piston and for the thermal analysis. The CAD model was discretised into 35573 nodes and 20441 elements, as shown in Figure 10. The boundary conditions were applied to the discretised model, followed by processing and postprocessing. The aluminium **4032-T6** 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.

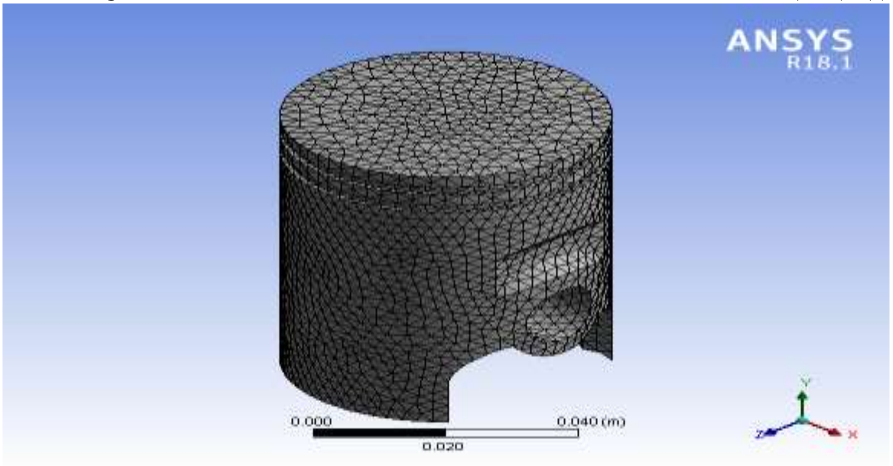

Figure 10. A meshed model of the piston

3. Results and Discussion

3.1 Microstructural Analysis

The SEM micrograph of the aluminium piston material is shown in Figures 11-13 for points 2,3 and 4, respectively. Table 4 shows the analysed EDS of the points 2,3 and 4. Aluminium is the predominant material present in the recycled aluminium alloy. The presence of C and O indicates the existence of adventitious carbon and oxygen on the surface of the aluminium in all the points.

The EDS analysis, as shown in Table 2, indicates that the material is mainly aluminium with alloying elements and few impurities. The impurities at low levels are beneficial to the recycled aluminium in terms of structural and textural properties and catalytic performance.

Magnesium was reported to reduce the alumina acidity and changes the catalytic activity and selectivity in acid-catalysed reactions. Magnesium also prevents the formation and deposition of coke and increases catalytic stability during methane steam reforming or ethanol steam reforming [22]. Al-Mg-Mn aluminium alloys were reported to have exceptional performance in extreme environments [23]. The recycled EOL aluminium alloys were found to contain magnesium and manganese in trace amounts.

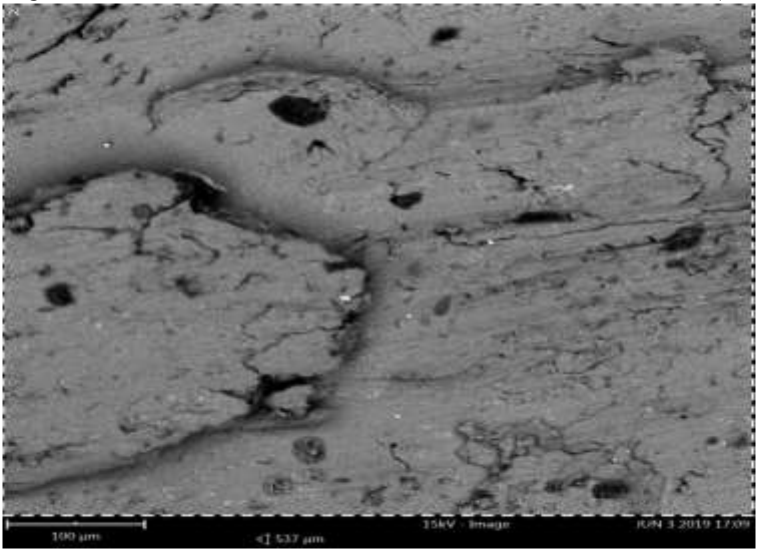

Figure 11. SEM-EDS micrograph of the recycled aluminium for point 2

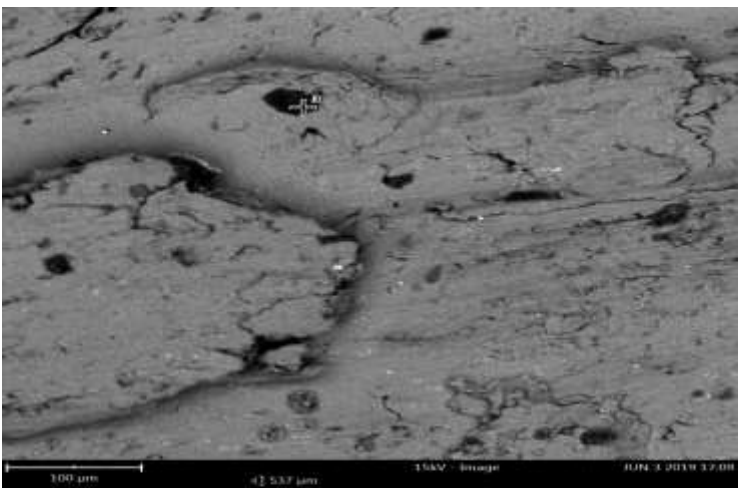

Figure 12. SEM-EDS micrograph of the recycled aluminium for point 3

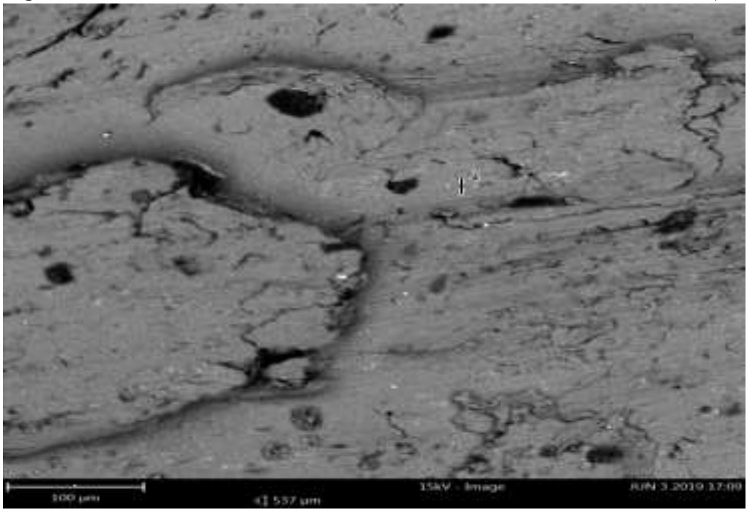

Figure 13. SEM-EDS micrograph of the recycled aluminium for point 4

Table 4. EDS of the points analysed

		Weight, %		
Element Symbol	*Element Name*	*Point 2*	*Point 3*	*Point 4*
Al	*Aluminium*	*52.78*	*3.99*	*63.43*
C	*Carbon*	*39.97*	*73.05*	*28.24*
O	*Oxygen*	*2.88*	*14.37*	*2.04*
Si	*Silicon*	*0.95*	*0.61*	*1.23*
Mg	*Magnesium*	*0.96*	*0.43*	*0.63*
Fe	*Iron*	*0.35*	*0.10*	*0.25*
Na	*Sodium*	*0.64*	*0.78*	*0.57*
N	*Nitrogen*	*0.84*	*6.28*	*2.17*
Zn	*Zinc*	*0.14*	-	-
Mn	*Manganese*	*0.17*	-	*0.45*
S	*Sulphur*	*0.15*	*0.28*	*0.55*
P	*Phosphorus*	*0.11*	*0.11*	*0.42*
Ti	*Titanium*	*0.06*	-	-

3.2 Thermal analysis of the piston

The thermal analysis for the aluminium piston was conducted using the ANSYS version R18.1 software. The piston was subjected to a thermal load of 500˚C and pressure of 5MPa. The temperature distribution profile, von Mises, of the piston were evaluated.

3.2.1 Temperature distribution profile

Figure 14 shows the temperature profile distribution of the piston. The maximum temperature of 500 ˚C was found on the piston crown while the temperature distribution along with the piston skirt varied from 498.5 ˚C below the crown to 486.6 ˚C below the piston pinhole.

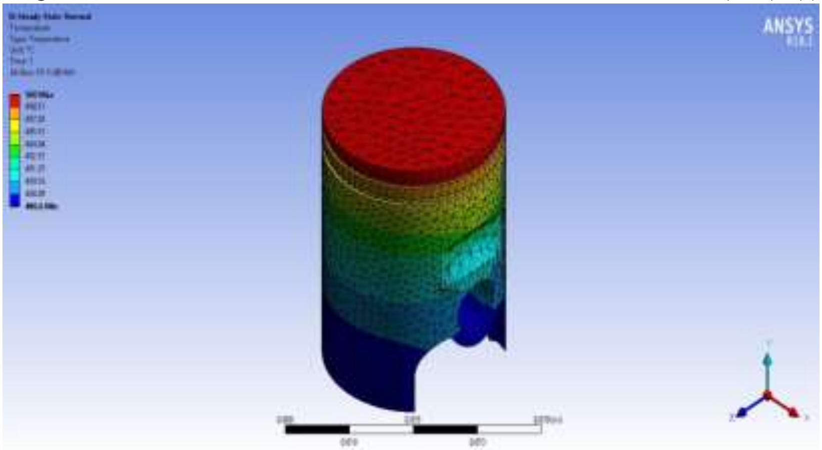

Figure 14. Temperature distribution of the piston

3.2.2 Von Mises stress

The von Mises stress is used to ascertain if a given material will yield or fracture. The von Mises criterion stipulates that if the von Mises stress of a material under load is equal or higher than the yield limit of the same material under simple tension, then the material will yield. In the analysis, the von Mises stress obtained for the piston was 1.8811×10^9 Pa at maximum and 5.6489×10^6Pa at minimum, respectively. Thus the von Mises of 1.8811×10^9 Pa obtained from the simulation is above the stated value of yield stress of 315 $x10^6$ Pa for the Aluminium alloy. The Von-Mises stress obtained indicates that the material will yield.

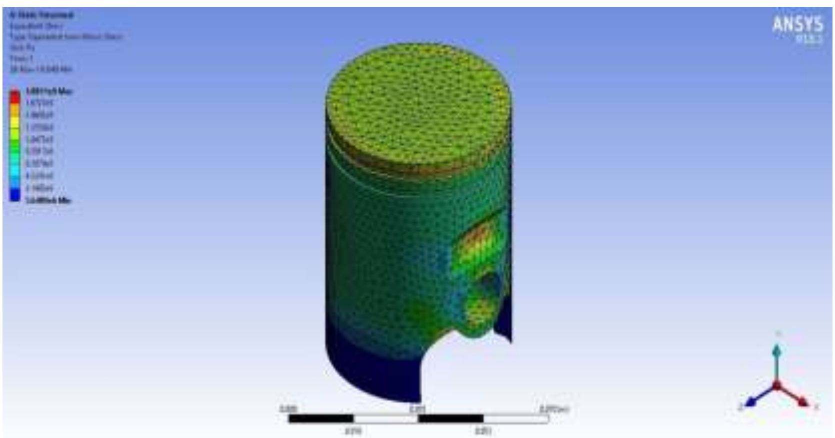

Figure 15. von Mises stress of the Piston

3.2.3 Equivalent elastic strain

The elastic strain is the limit for the values of strain up to which the object will recover and come back to the original shape upon the removal of the load. Figure 16 shows the equivalent elastic strain of the piston. The maximum and minimum equivalent elastic strain when the piston was subjected to both thermal load of $500^{O}C$ and pressure load of 5MPa are 0.026722m/m and 0.00012524m/m respectively.

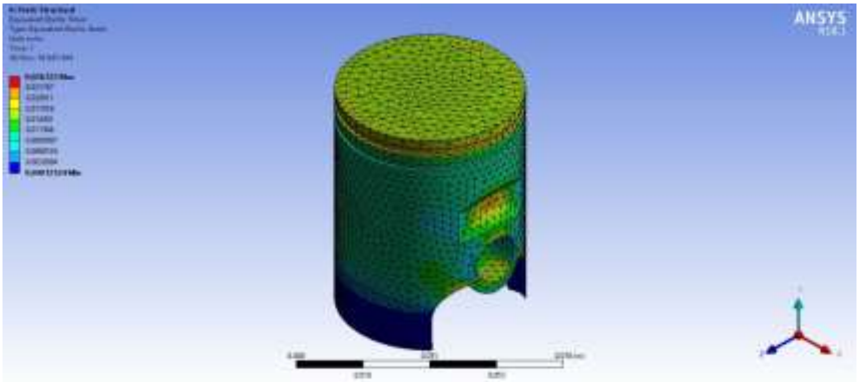

Figure 16. Equivalent Elastic Strain of the piston

3.2.4 Total deformation of the piston

Figure 17 shows the total deformation of the piston. The total deformation is an indication of the displacement of the material when subjected to thermal and pressure loads. The maximum deformation obtained for the piston is 0.00067336m while the minimum deformation was obtained as 3.8575×10^{-9}m.

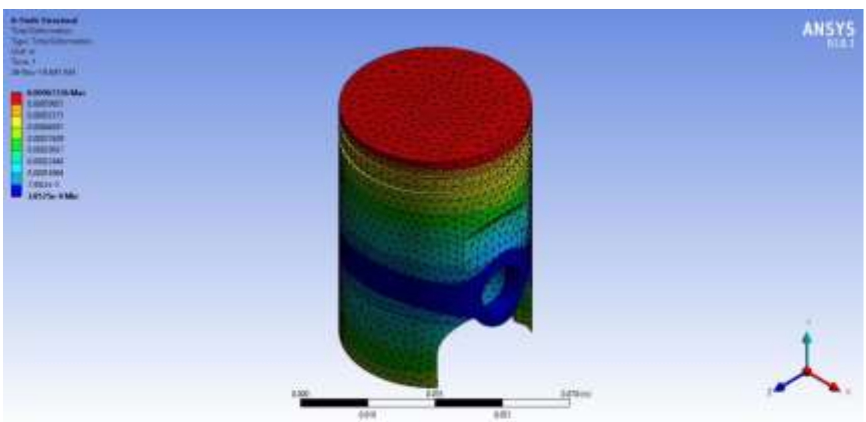

Figure 17. Total deformation of the piston

4 Conclusion

This study on the fabrication and Assessment of a motorcycle piston using the traditional sand- casting method is concluded with the following remarks:

1. The traditional sand-casting method used in the fabrication of the aluminium piston mould was found to be cost-effective, flexible and replicable.

2. End-of-Life recycled aluminium piston materials used in this study were found to contain the much needed alloying metals such as magnesium and manganese, which are beneficial to the aluminium alloy piston.
3. The SEM-EDS conducted on the recycled EOL aluminium revealed that aluminium is the most predominant material followed by oxygen as tabulated in Table 4.
4. The presence of C and O indicates the existence of adventitious carbon and oxygen on the surface of the aluminium in all the points.
5. The von Mises stress obtained for the piston revealed that the piston would yield.
6. The maximum total deformation of 0.00067336m, which is equivalent to 0.67336mm shows that the piston displacement during service life is negligible.
7. The equivalent elastic strain limits obtained are negligible.

References

[1] Y. X. Wang, Y. Q. Liu, and H. Y. Shi, "Finite Element Static and Dynamic Analysis for a Piston," Adv. Mater. Res., vol. 97–101, pp. 3323–3326, Mar. 2010.

[2] V. K. Yadav and Y. Mishra, "Design and structural analysis of a ceramic coated petrol engine piston using finite element method: A Review," Int. J. Eng. Tech. Res., vol. 3, no. 5, pp. 367–370, 2015.

[3] S. Angel et al., "1997 Economic Census: Carburetor, Piston, Piston Ring, and Valve Manufacturing," 1997.

[4] G. Sinha, "A Project report on manufacture of Automobile Piston," Patna (Bihar), 2012.

[5] J. Varnell et al., "Understanding the influence of carbon addition on the corrosion behavior and mechanical properties of Al alloy 'covetics,'" J. Mater. Sci., vol. 54, no. 3, pp. 2668–2679, 2019.

[6] Okokpujie, I. P., Okonkwo, U. C., Bolu, C. A., Ohunakin, O. S., Agboola, M. G., & Atayero, A. A. (2020). Implementation of multi-criteria decision method for selection of suitable material for development of horizontal wind turbine blade for sustainable energy generation. Heliyon, 6(1), e03142.

[7] P. Sharma, S. Sharma, and D. Khanduja, "A study on microstructure of aluminium matrix composites," J. Asian Ceram. Soc., vol. 3, no. 3, pp. 240–244, Sep. 2015.

[8] "Automotive Mechanics: Pistons, connecting rods and bearings." [Online]. Available: https://pautomotivemechanics.blogspot.com/2011/06/pistons-connecting-rods-and-bearings.html. [Accessed: 08-Oct-2019].

[9] F. U. Ozioko, “Casting of Motorcycle Piston from Aluminium Piston Scrap using Metallic Mould,” Leonardo Electron. J. Pract. Technol., no. 21, pp. 82–92, 2012.

[10] H. F. Mahdy, T. A. Enab, A. M. Galal, and M. Samuel, “Experimental Study of Manufacturing Aluminum Alloy Pistons Using Vertical Centrifugal Casting Process,” vol. 7, no. 8, pp. 198–203, 2016.

[11] S. M. Ali, “The effect of reinforced SiC on the mechanical properties of the fabricated hypoeutectic Al-Si alloy by centrifugal casting,” Eng. Sci. Technol. an Int. J., Mar. 2019.

[12] C. O. Agbo, “Design and Production Techniques for an Internal Combustion Engine Piston: The Nigerian Experience,” University of Nigeria, 1997.

[13] K. Kumar, H. Kalita, D. Zindani, and J. P. Davim, “Casting,” Springer, Cham, 2019, pp. 37–52.

[14] M. Senthil Kumar, R. V. Mangalaraja, R. Senthil Kumar, and L. Natrayan, “Processing and Characterization of AA2024/Al2O3/SiC Reinforces Hybrid Composites Using Squeeze Casting Technique Characterizations of Metal Matrix Composites in Engineering Application View project,” Iran. J. Mater. Sci. Eng., vol. 16, no. 2, pp. 55–67, 2019.

[15] Y. Zhong, G. Su, and K. Yang, “Microsegregation and Improved Methods of Squeeze Casting 2024 Aluminium Alloy,” J. Mater. Sci. Technol., vol. 19, no. 05, pp. 413–416, Oct. 2009.

[16] T. R. Vijayaram, S. Sulaiman, A. M. S. Hamouda, and M. H. M. Ahmad, “Fabrication of fiber reinforced metal matrix composites by squeeze casting technology,” J. Mater. Process. Technol., vol. 178, no. 1–3, pp. 34–38, Sep. 2006.

[17] R. Etemadi, B. Wang, K. M. Pillai, B. Niroumand, E. Omrani, and P. Rohatgi, “Pressure infiltration processes to synthesize metal matrix composites – A review of metal matrix composites, the technology and process simulation,” Mater. Manuf. Process., vol. 33, no. 12, pp. 1261–1290, Sep. 2018.

[18] V. Sampath, N. Ramanan, and R. Palaninathan, “Modeling of Liquid Metal Infiltration of Porous Fiber Preform During Squeeze Casting,” Mater. Manuf. Process., vol. 21, no. 5, pp. 495–505, Aug. 2006.

[19] M. F. Alam, “Squeeze casting as alternative fabrication process for carbon fiber reinforced aluminium matrix composites,” University of Ottawa, 2013.

[20] M. Alhaji Ibrahim, Y. Sahin, A. Yusuf Gidado, and M. Said, “Mechanical Properties of Aluminium Matrix Composite Including SiC/Al2O3 by

Powder Metallurgy-A Review," 2019.

[21] M. Palanivendhan, J. Chandradass, A. Rajendran, N. M. Govindarajan, and M. A. Krishnaa, "Experimental Investigation of Alumina Reinforced Copper Metal Matrix Composite by Stir Casting Method," Int. J. Veh. Struct. Syst., vol. 11, no. 1, pp. 79–82, 2019.

[22] Y. F. Adans, A. R. Martins, R. E. Coelho, C. F. das Virgens, and A. D. Ballarini, "A Simple Way to Produce γ-Alumina From Aluminum Cans by Precipitation Reactions," Mater. Res., vol. 19, no. 5, pp. 977–982, Jul. 2016.

[23] D. Vonica, P. Moldovan, C. Stanica, M. Butu, M. Ciurdas, and M. Pana, "Investigations of the nature of non-metallic inclusions in Al-Mg-Mn Alloys," U.P.B. Sci. Bull, vol. 75, no. 4, 2013.