Modelling of a Conventional Piston of a Single Cylinder Four-Stroke Diesel Engine by Using SolidWorks

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ORIGINAL RESEARCH ARTICLE
Received: 19-SEP-2021; Reviewed: 28-OCT-2021; Accepted: 20-DEC-2021
http://dx.doi.org/10.46792/fuoyejet.v7i1.697

Abstract- This paper presents a 3D modelling of a conventional piston of a single cylinder four-stroke diesel engine using ZS1115NM diesel engine specification. Piston in internal combustion engine (ICE) is a circular piece of metal which converts the rotary movement of the crankshaft into reciprocating motion thereby exerting a force on the air-fuel mixture in the cylinder. It converts thermal energy into mechanical energy in an ICE. The methodology applied was analytical design and modelling of the piston using SOLIDWORKS 2013 3D Computer Aided Design (CAD) software. This method was used because it provided a step by step designing of the various elements of the piston. The material chosen for the piston is an aluminium alloy designated as A92618 or simply A2618, due majorly to its high coefficient of thermal expansion (CTE) which enables the piston withstand high thermal stress without cracking or failure. Another important reason is that it has a high thermal conductivity (approximately 3 times than that of cast iron). It is seen that with given engine specification a suitable material for designing a conventional piston is chosen and the model manufactured.

Keywords- 3D modelling, ZS1115NM, Internal combustion engine, SOLIDWORKS 2013, A2618, Coefficient of thermal expansion.

1 INTRODUCTION

Piston in an internal combustion engine (ICE) is a circular piece of metal which converts the rotary motion of the crank-shaft into reciprocating motion in the cylinder thereby exerting a force on the air-fuel mixture contained in the cylinder (Dolan, 1991). Pistons have compression and oil control rings preventing oil from entering the combustion-chamber including the fuel-air from mixing with the oil (Röhrle, 1995). Most pistons fitted in a cylinder have piston rings (Shirisha & Sravani, 2016). There may be two or more compression rings acting as seals or barriers between the piston and cylinder-wall. There may also be one or two oil control-rings below the compression-rings (Fig. 1).

The piston head is classified as flat, bulged or otherwise shaped. Pistons are forged or cast and their shapes are normally rounded (Röhrle, 1995). The preferred materials for gasoline and diesel engine pistons are aluminium alloys because they possess low density, high thermal conductivity, simple fabrication techniques (casting and forging), simple machinability, high-reliability and very good recycling-characteristics (Lokesh *et al.*, 2015). The continuing development of modern diesel and gasoline engines leads to specific objectives for further piston development (Shirisha & Sravani, 2016): reduction of piston weight, increase of mechanical and thermal load capacity, lower friction including improved scuffing resistance, etc. Moreover, the basic requirements for durability, low-noise level and minimum oil-consumption have to be considered.

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Section C- MECHANICAL/MECHATRONICS ENGINEERING & RELATED SCIENCES
Can be cited as:
Isaac F.O. and Abu L. (2022): Modelling of a Conventional Piston of a Single Cylinder Four-Stroke Diesel Engine by Using SolidWorks, *FUOYE Journal of Engineering and Technology* (FUOYEJET), 7(1), 65-68. http://dx.doi.org/10.46792/fuoyejet.v7i1.697

Fig. 1: Different elements of the piston

These goals are achieved by a targeted combination of high-performance aluminium piston materials, novel piston designs including the application of innovative coating technologies (Akalin & Newaz, 1998).

2 MATERIALS AND METHOD

Pistons are made of either aluminium alloy, aluminium, cast-iron or steel (Davis, 1999). The cylinder-head is typically made of cast-iron, with either lamellar or compacted graphite (Davis, 1998). Nodular cast-iron is used for manufacturing exhaust manifolds with the addition of silicon and molybdenum to improve the thermo-mechanical fatigue and oxidation properties. Cast steel is also used for these components (Davis, 1993).

In selecting the substrate material for designing piston of a ZS1115NM single cylinder, inline and four-stroke direct injection diesel engine, the following qualities of materials were considered (Dolan, 1991):

(a) Strength to withstand the high pressure;
(b) Minimum weight to withstand the inertia forces;

(c) Good heat conductivity to reduce the risk of detonation and allowing higher compression ratios;
(d) High coefficient of thermal expansion: The substrate material has a high coefficient of thermal expansion (CTE) to prevent cracking or failure of the piston;
(e) Effective oil sealing in the cylinder;
(f) Sufficient bearing area to prevent undue wear;
(g) High speed reciprocation without noise;
(h) Sufficient rigid construction to withstand thermal and mechanical distortions; and
(i) Sufficient support for the piston pin.

The above qualities require an aluminium alloy for the piston material. The piston material chosen for this study is A92618 (Ashby, 1999). Tables 1 and 2 show the chemical composition and mechanical/physical properties of the A92618, respectively (Ashby, 2005).

Table 1. Chemical Composition of A92618 Aluminium Alloy

Alloying Elements	Copper	Manganese	Iron	Nickel	Silicon	Titanium	Aluminium
Percentage Composition	2.3	1.6	1.1	1.0	0.18	0.07	93.75

Table 2. Mechanical Properties/Physical Properties of A92618 Aluminium Alloy

Property	Mass density (ϱ)	Yield tensile strength	Ultimate tensile strength	Compressive strength	Shear strength	Fatigue strength
Value	2760 kg/m^3	372 MPa	441 MPa	441 MPa	260 MPa	125 MPa
Young modulus (E)	Shear modulus (G)	Poisson's ratio (ν)	Thermal conductivity (k)	Coefficient of thermal expansion (α)	Specific heat	Liquidus temperature
74.5 MPa	27 GPa	0.33	146 W/mK	22.3 x 10^{-6}/K	875 J/kgK	638 ^{0}C

2.1 Analytical Design of the Piston

Fig. 2 shows the cross-sectional view of the conventional piston to be modelled (Tadala *et al.*, 2016).

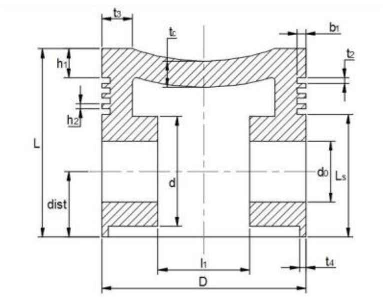

Fig. 2: Cross section of the model conventional piston

Thickness of Piston Head or Crown, t_C: According to Grashoff's formula, the piston head thickness t_C is given by,

$$t_C = \sqrt{\frac{3p_{max}D^2}{16\sigma_t}} \quad (1)$$

Where p_{max} is the maximum gas pressure (Pa),
D = cylinder bore or outside diameter of the piston (m),
σ_t = permissible tensile stress for the piston material (Pa)

Piston Rings: From Fig. 2, we have total number of rings equals 4, number of compression rings equals 3 and number of oil ring equals 1.

Radial Thickness of Piston Ring t_1:

$$t_1 = D\sqrt{\frac{3p_w}{\sigma_p}} \quad (2)$$

Where p_w = allowable radial pressure of the gas on the cylinder wall taken as 0.025 MPa;
σ_P = permissible bending or tensile stress for cast iron rings = 84 MPa

Axial Thickness of Piston Ring, t_2:

$$t_2 = \frac{D}{10n_R} \text{ or } = 0.7t_1 \quad (3)$$

Where n_R = number of rings taken as 4

Length of Piston Pin in the Connecting Rod Bushing, l_1

$$l_1 = 0.45D \quad (4)$$

Width of Top Land h_1:

$$h_1 = 1.2\, t_C \quad (5)$$

Width of other Ring Lands h_2:

$$h_2 = 0.75t_2 \quad (6)$$

Piston Barrel: Piston Barrel thickness t_3 at top end

$$t_3 = 0.03D + b_1 + 4.5 \quad (7)$$

$$b_1 = t_1 + 0.4 \quad (8)$$

Where b_1 = radial depth of piston ring groove (mm)

Piston Barrel thickness t_4 at open end

$$t_4 = 0.25\, t_3 \quad (9)$$

Piston Skirt:

Length of the piston skirt, l_s = 0.6 D (10)

Total Length of Piston L = Length of the piston skirt + Length of Ring Section + Top Land

$$= l_s + (4\, t_2 + 3\, h_2) + h_1 \quad (11)$$

The length of piston usually varies from D and 1.5D.

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Piston Pin: Outside diameter d_0 of piston pin:

$$d_0 = 0.3D \qquad (12)$$

Piston Boss diameter $d = 1.5\ d_0$ (13)

Although, d_0 is given in the owner's manual. The value is 36 mm.

Inside diameter d_1 of piston pin:

$$d_1 = 0.6\ d_0 \qquad (14)$$

Centre of Pin: Centre of pin is 0.02D to 0.04D above the centre of the skirt.

$$\text{Centre of pin} = 0.04D + 0.5\ l_s \qquad (15)$$

The specifications for designing and modelling the conventional piston of the diesel-engine with the help of SOLIDWORKS software were that of ZS1115NM single cylinder, inline and four-stroke direct injection diesel engine manufactured by Changchai Company Ltd, China. Table 3 shows the engine specifications (ZS1115NM, 2015).

Table 3. Engine Specification

Item	Specification
Engine model	ZS1115NM
Type	Single cylinder, four stroke, horizontal type, direct injection
Cylinder bore (D) (mm)	115
Piston stroke (L_S) (mm)	115
Piston displacement (V_s) (litre)	1.19
Compression ratio (c.r)	17:1
Rated output/brake power (b.p) (kW)	15.7
Rated speed (N)(Rev/min)	2200
Brake specific fuel consumption (bsfc) (g/kWh)	≤ 244.8
Specific lube oil consumption (g/kWh)	≤ 2.04
Lubricating method	Single circuit
Cooling method	Water cooled, evaporative
Cooling system	Radiator, natural convection
Starting method	Electric starting or hand cranking
Fuel injection pressure (MPa)	18.13 ± 0.49
Net weight (kg)	205
Overall dimension (L x W x H) (mm)	965 x 457 x 713
Mean piston speed (c_m) (m/s)	8.433
Fuel injection timing before TDC	22^0
Fuel type	Diesel
Chemical formula	$C_{14.4}H_{24.9}$
Connecting rod length (L_R) (mm)	258.5
Intake valve closes after TDC	38^0

Equations (1) – (15) can only be used in designing the piston if the maximum gas pressure p_{max} is known. The maximum gas pressure which was calculated by using the Diesel cycle was 10.2 x 10^6 N/m² or 10.2 N/mm² (Isaac, 2021). From Table 2, yield tensile strength of the material used for the piston, σ_t = 372 N/mm². Table 4 summarizes the sizes obtained from the analytical design of the piston.

Table 4. Piston Analytical Design Sizes

S/N	Piston parameter	Size obtained (mm)
1	Cylinder bore, D	115
2	Thickness of piston head, t_C	8.25
3	Radial thickness of piston ring, t_1	3.436
4	Axial thickness of piston ring, t_2	2.405
5	No of piston rings, n_R	4
6	Width of top land, h_1	9.9
7	Width of ring land, h_2	1.80375
8	Radial depth of piston ring groove, b_1	3.836
9	Thickness of piston barrel at top end, t_3	11.786
10	Thickness of piston barrel at open end, t_4	2.9465
11	Piston pin diameter, d_0	34.5
12	Diameter of piston boss, d	51.75
13	Length of Skirt, l_s	69
14	Total length of piston, L	93.93
15	Centre of pin above the centre of the skirt	39.10
16	Inside diameter of piston pin, d_1	20.7
17	Length of piston pin in the connecting rod bushing, l_1	51.75

2.2 Solidworks Modelling of the Conventional Piston

The sizes obtained from the analytical design of the piston in Table 4 were used in modelling the conventional piston in Solidworks 2013 CAD Software (James, 2016). Figs. 3 and 4 show the different views of the modelled conventional piston.

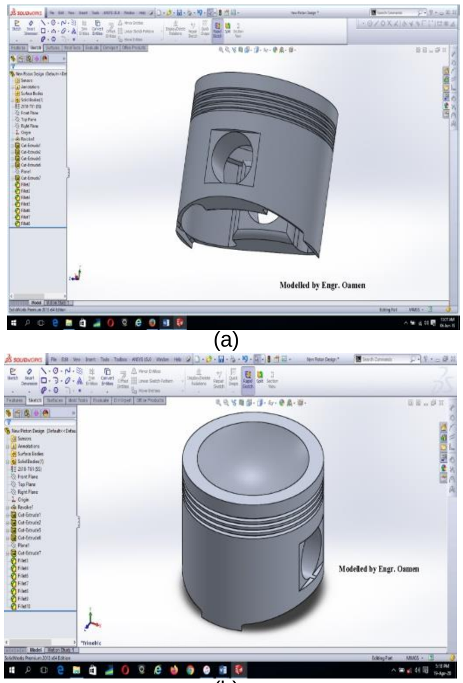

Fig. 3: (a) Rotated view of the 3D modelled conventional piston (b) Isometric view of the 3D modelled conventional piston

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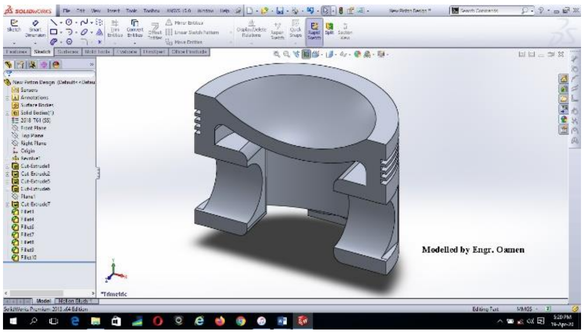

Fig. 4: Sectional view of the modelled conventional piston

3 Result and Discussion

Figs. 3 and 4 show the result of modelling conventional piston of ZS1115NM single cylinder, inline and four-stroke direct injection diesel engine using SOLIDWORKS 2013 CAD. From Table 4, it is seen that the thickness of piston head or crown, t_c is 8.25 mm. This size is common with pistons used in ICEs, especially diesel engines. Considering the special characteristics of piston made of aluminium alloys, it is better than the ones made of cast iron.

4 CONCLUSION

Having modelled the conventional piston of a single cylinder, inline and four stroke direct injection diesel engine using SOLIDWORKS 2013 CAD, it can be concluded that with given engine specification a suitable material for designing a conventional piston of diesel engine is chosen and the model manufactured.

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