STATIC AND THERMAL ANALYSIS OF FOUR STROKE PETROL ENGINE PISTON USING COMPOSITE MATERIALS

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Abstract

The main aim of this work is to predict the design performance based on the static and thermal behavior of 4 stroke petrol engine piston under various operating conditions. Usually the pistons are made of Aluminium for lightweight, thermal conductivity. But it has poor hot strength and high coefficient of expansion, which makes it less suitable for high temperature applications. In this project, Aluminium alloy i.e AL 4032 and ZAMAK 3 are used as an alternative for aluminium. A 3D model was made using catia V5 and Structural and thermal analysis was done on ANSYS 15.0. The analysis is done using three materials namely aluminium ,AL 4032 and ZAMAK 3.comparison is done for the three materials to verify the best material for the designed piston. In the present thesis,work has been considered on the 3 aspects they are, Total deformation, Equivalent strain**,** Equivalent stress, Heat flux.

Keywords: 4 stroke petrol engine piston, CATIA and analysis is done on ANSYS software, changing materials.

1.Introduction

The piston is a disc which reciprocates within a cylinder. It is either moved by the fluid or it moves the fluid which enters the cylinder. The main function of the piston of an internal combustion engine is to receive the impulse from the expanding gas and to transmit the energy to the crankshaft through the connecting rod. The piston must also disperse a large amount of heat from the combustion chamber to the cylinder walls. The piston of internal combustion engines are usually of trunk type:

pistons are open at one end and consists of the following parts:

1. Head or crown: The piston head or crown may be flat, convex or concave depending upon the design of combustion chamber. It withstands the pressure of gas in the cylinder.

2. Piston rings: The piston rings are used to seal the cyliner in order to prevent leakage of the gas past the piston.

3. Skirt: The skirt acts as a bearing for the side thrust of the connecting rod on the walls of cylinder.

4. Piston pin: It is also called gudgeon pin or wrist pin. It is used to connect the piston to the connecting rod.

The piston is subjected to highly rigorous conditions and must therefore have enormous strength and heat resistant properties to withstand high gas pressure. Its construction should be rigid enough to withstand thermal and mechanical distortion. To maintain piston temperature within limits, the heat from the crown of piston must be dissipated quickly and efficiently to the rings and bearing area and then to the cylinder walls. The profile of the piston head is dependent on the design of combustion chamber.

2. Literature Survey

Manjunatha. T. R [**1**] described the design and analysis of cylinder and piston of a two stage reciprocating Air Compressor to the taken specifications for both low pressure and high pressure stages. A finite element model for cylinder and piston is built and analysis of these components is carried by using ANSYS, for both low pressure and high pressure stages during the suction and compression stroke. So as to identify the location of maximum stress concentration and to identify the areas those are likely to fail.

Vaibav V. Mukkawar [2] described the stress distribution of two different aluminum alloys piston by using CAE Tools. The specifications used for the study of these pistons belong to four stroke single cylinder engine of Bajaj Pulsar 220CC motorcycle. He illustrated the procedure for analytical design of two different aluminum alloy pistons. The results predict the maximum stress and critical region on the different aluminum alloy pistons using CAE Tools. A parametric model of Piston is modeled using Solid works 2014 software and analysis of that model is carried out by using ANSYS 14.5 Software. The best aluminum alloy material is selected based on parameters like Von Misses Stress and strain, Deformation, Factor of safety and weight reduction for two wheeler piston were done in ANSYS 14.5 software.

Isam Jasim Jabir and Ajeet Kumar Rai **[3]** presented a work on piston and piston ring are designed for a single cylinder four stroke petrol engine using CATIA V5R20 software. Complete design is imported to ANSYS 14.5 software then analysis is performed. Three different materials have been selected for structural and thermal analysis of piston. For piston ring two different materials are selected and structural and thermal analysis is performed using ANSYS 14.5 software. Results are shown and a comparison is made to find the most suited design.

Vaishali R. Nimbarte, Prof. S.D. Khamankar **[4]** investigated and analyzed the stress distribution of piston at actual engine condition. Pressure analysis, thermal analysis and thermo-mechanical analysis is done. The parameter used for the analysis is operating gas pressure, temperature and material properties of piston. In I.C. Engine piston is most complex and important part therefore for smooth running of vehicle piston should be in proper working condition. Piston fail mainly due to mechanical stresses and thermal stresses. Analysis of piston is done with boundary conditions, which includes pressure on piston head during working condition and uneven temperature distribution from piston head to skirt. The analysis predicts that due to temperature whether the top surface of the piston may be damaged or broken during the operating conditions, because damaged or broken parts are so expensive to replace and generally are not easily available.

Abino John, Jenson T Mathew **[5]** used Aluminum Silicon Carbide (AlSic), an aluminum matrix composite for piston an alternative for aluminum. A 3D model was made using CATIA v6 and Structural and thermal analysis was done on ANSYS14. Compared to Aluminum, AlSiC has better abrasion resistance, creep resistance, dimensional stability, exceptionally good stiffness-to-weight and strength-to-weight ratios and better high temperature performance. Fabrication of piston using AlSiC is also easier than using aluminum.

Ajay Raj Singh, Dr. Pushpendra Kumar Sharma **[6]** described the stress distribution and thermal stresses of three different aluminum alloys piston by using finite element method (FEM). The parameters used for the simulation are operating gas pressure, temperature and material properties of piston. The specifications used for the study of these pistons belong to four stroke single cylinder engine of Bajaj Kawasaki motorcycle. This paper illustrates the procedure for analytical design of three aluminum alloy pistons using specifications of four stroke single cylinder engine of Bajaj Kawasaki motorcycle. The results predict the maximum stress and critical region on the different aluminum alloy pistons using FEA. It is important to locate the critical area of concentrated stress for appropriate modifications. Static and thermal stress analysis is performed by using ANSYS 12.1. The best aluminum alloy material is selected based on stress analysis results. The analysis results are used to optimize piston geometry of best aluminum alloy.

Parag C. Thanare, R. G. Telrandhe **[7]** described the stress distribution on piston head by using FEA. The main objective is to investigate and analyze the thermal stress distribution of piston, piston rings at the real engine condition during combustion process. They mainly focused on the critical investigation of original piston of engine and its performance along with the different materials coatings with different thickness, mesh optimization with using finite element analysis technique to predict the higher stress and critical region on the component. Using Computer Aided Design(CAD), Pro/ENGINEER software the structural model of a piston is developed. Furthermore, the finite element analysis performed using ANSYS.

3. Theoritical calcutalions

1. Thickness of Piston Head

The piston thickness of piston head calculated using the following Grashoff's formula.

$$t_H = \sqrt{\frac{3p.D^2}{16\sigma_t}} \text{ (in mm)}$$

Where,

P= maximum pressure in N/mm^2= 5 N/mm^2

D= cylinder bore/outside diameter of the piston in mm.

D = 85 mm.

σ_t = permissible tensile stress for the material of the piston.

Thickness of Piston Head (t_H)= 6.25mm

2. Heat Flow Through the Piston Head (H):

The heat flow through the piston head is calculated using the formula

$$H = C * HCV * M * BP = 3478.28 \text{ W}$$

$$t_H = \frac{H}{12.56k(T_C - T_E)} \text{ (in mm)}$$

= 26 mm

Where,

H= Heat flow through the piston head.

C=Constant heat supplied to engine(C=0.05).

HCV= Higher calorific value of petrol ($HCV=42\times10^3$ KJ/Kg).

M= Mass of fuel used per cycle ($M=41.7 \times10^{-6}$ kg/BP/sec).

BP= Brake power (BP=39.72 kW).

K= Thermal conductivity of material which is 140 W/mk.

Tc = Temperature at centre of piston head in °C.

Te = Temperature at edges of piston head in °C.

3. Radial Thickness of Ring

$$t_1 = D\sqrt{\frac{3p_w}{\sigma_t}}$$

= 2.219mm

Where,

D = Cylinder bore.

D = 85 mm.

P_w = Pressure of gas on the cylinder wall (nearly taken as 0.025 Mpa to 0.042Mpa).

$\boldsymbol{\sigma}_t$ = Allowable bending tensile stress (110Mpa for aluminium alloy).

4. Axial Thickness of Ring

The thickness of the rings may be taken as

$t_2 = 0.7t_1$ to t_1 = 1.55 to 2.219mm

5. Width of the Top Land

The width of the top land varies from

$b_1 = t_H$ to $1.2t_H$ = 26 to 31.2 mm

6. Width of other Lands

Width of other ring lands varies from

$b_2 = 0.75t_2$ to 3 = 1.22 to 3 mm

7. Maximum Thickness of Barrel

$t_3 = 0.03D + b + 4.5$ mm = 8.03mm

Where,

b = radial depth of piston ring groove.

$b = t_1 + 0.4$

8.Piston wall thickness towards

$t_4 = 0.25t_3$ to $0.35t_3$ = 2.41 to 3.38 mm

9. Piston Pin:

Load on pin due to bearing pressure = $P_b * d_0 * t_1 =$ 956.25d_O

Where, t_1= 0.45D

10.Maximum load on piston due to gas pressure = $\frac{\pi}{4} D^2 \times p$ = 28372.5 N

Load on pin due to bearing pressure = maximum load on piston due to gas pressure

$956.25d_O = 28372.5$

$d_O = 30$ mm

Outside diameter of piston pin $d_o = 30$ mm

Inside diameter of piston pin $d_i = 0.6d_o = 0.6 \times 30 = 18$ mm

10. Maximum bending moment:

$$M = \frac{P*D}{8} = \frac{28372.5*85}{8} = 301.45*10^3 \text{ N-mm}$$

$$301.45*10^3 = \frac{\pi}{32}\left[\frac{(do)^4-(di)^4}{do}\right]\boldsymbol{\sigma}_B$$

$\sigma_b = 152.43$N/mm

4. Results & Discussions

Apply the Boundary conditions on the piston. The fixed supports are shown in detail in the figure and the pressure is applied at the top of the dome type piston.

4.1. Static Structural Analysis

4.1.1 Boundary conditions

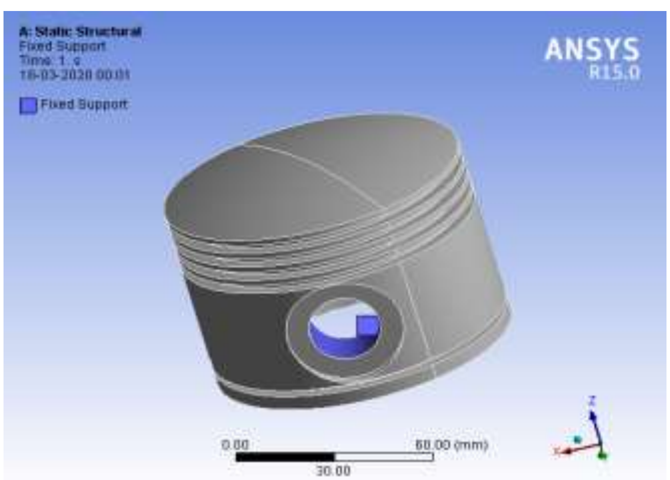

Fig 1. Fixed support at piston pin

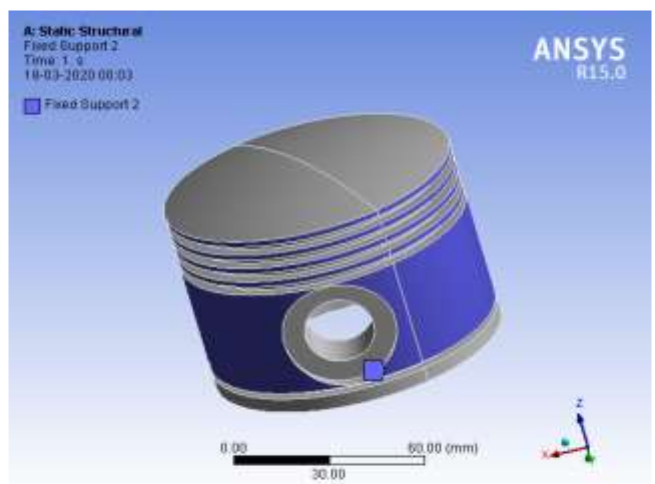

Fig 2. Fixed support to sidewalls

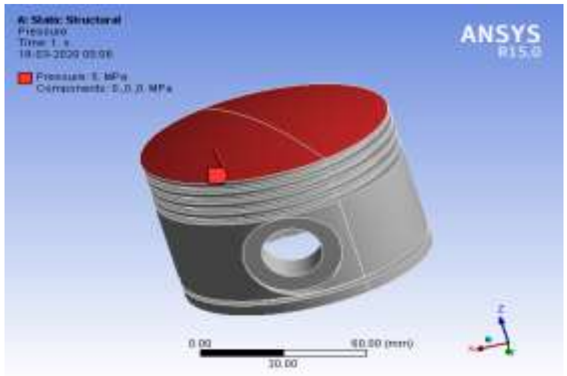

Fig 3. Pressure applied on piston crown.

Material 1: ALUMINIUM ALLOY

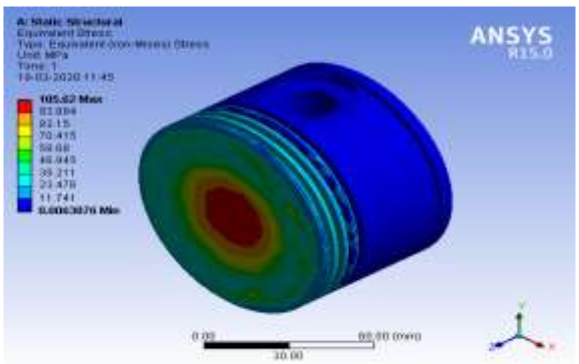

Fig 4 Equivalent stress

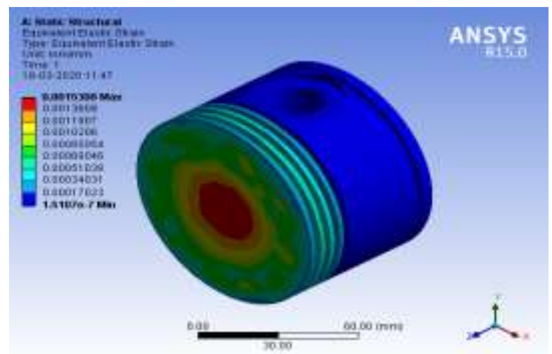

Fig 5 Equivalent strain

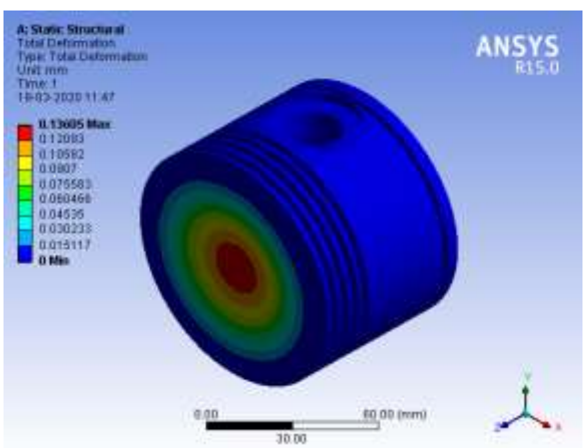

Fig 6 Deformation

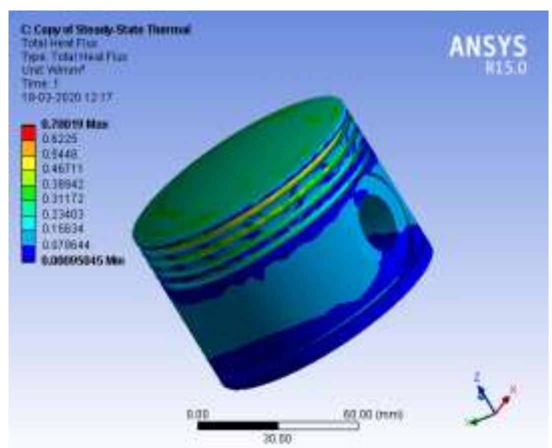

Fig 7 Heat Flux

MATERIAL 2: Al 4032

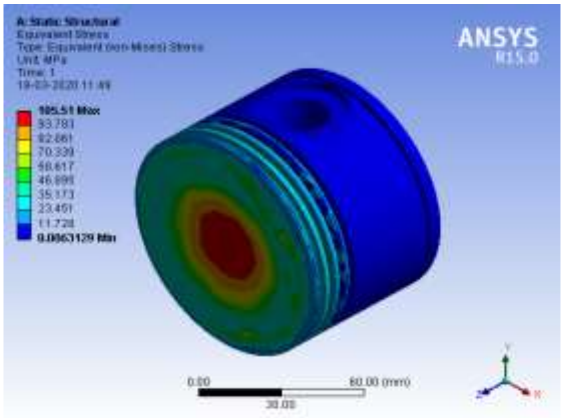

Fig 8 Equivalent stress

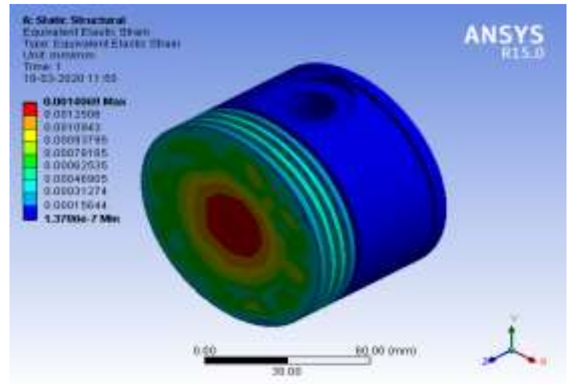

Fig 9 Equivalent strain

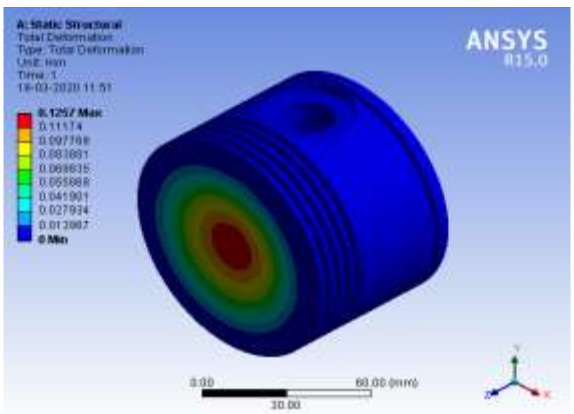

Fig.10 Deformation

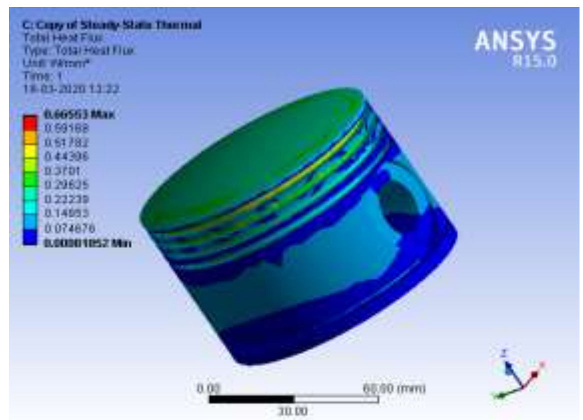

Fig.11 Heat Flux

Material 3:ZAMAK 3

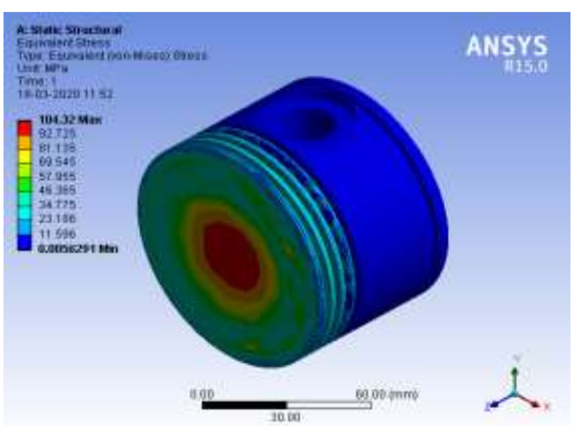

Fig.12 Equivalent stress

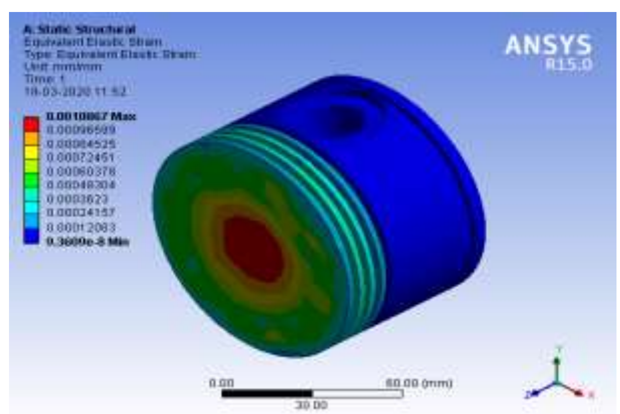

Fig.13 Equivalent strain

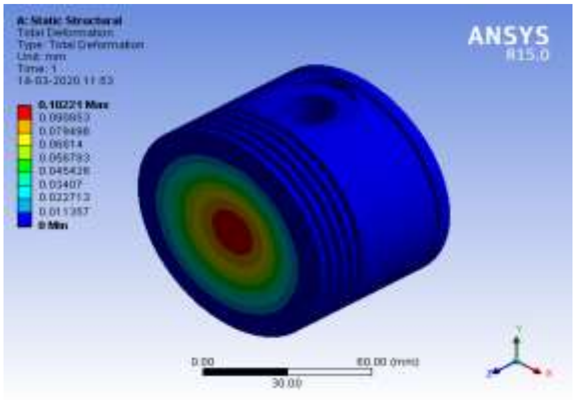

Fig.14 Deformation

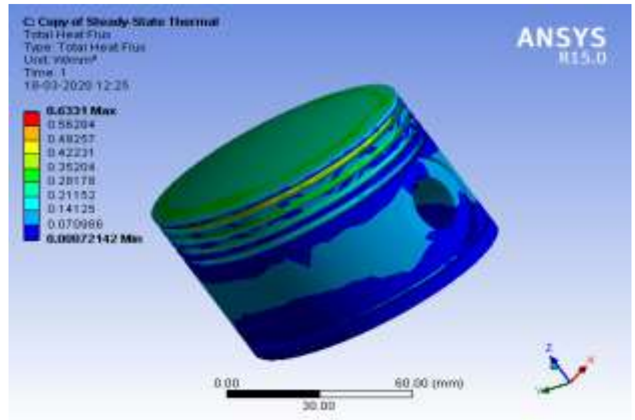

Fig.15 Heat flux

Summary of Results:

Table 1:-. Static and Thermal Analysis and Comparison of Aluminium Alloy, Al 4032 and Zamak 3 at pressure 5 bar

Material	Equivalent stress(Mpa)	Equivalent strain	Deformation(mm)	Heat flux(W/mm^2)
Aluminium	105.62	0.0015	0.1360	0.70019
Al 4032	105.51	0.00140	0.12	0.665
Zamak 3	104.32	0.0010	0.10	0.6331

Table 2:- Static and Thermal Analysis and Comparison of Aluminium,Al 4032 and Zamak 3 at 10 bar pressure.

Material	Equivalent stress(Mpa)	Equivalent strain	Deformation(mm)
Aluminium	211.24	0.003	0.27
Al 4032	211.01	0.0028	0.25
Zamak 3	208.63	0.00217	0.20

Table 3:- Static and Thermal Analysis and Comparison of Aluminium,Al 4032 and Zamak 3 at 15 bar pressure.

Material	Equivalent stress(Mpa)	Equivalent strain	Deformation(mm)
Aluminium	316.86	0.00459	0.408
Al 4032	316.52	0.00422	0.377
Zamak 3	312.95	0.00326	0.306

5. Conclusions:-

The present work deals with static and thermal analysis of piston made of three different materials such as Al, Al 4032 & ZAMAK 3 alloys by applying different pressures such as 5Mpa, 10Mpa and 15Mpa on the top of the piston. The following conclusions were drawn from this work:

1. It is observed from static analysis that less stresses are induced when lower pressure act on the piston head compared to higher pressures.
2. Stresses increases with increase in pressure, so lower pressure 5Mpa is more beneficial compared to higher pressures 10Mpa and 15Mpa.
3. A piston made of ZAMAK 3 exhibits lower stresses and minimum deformation in comparison with piston made of other materials.

4. Higher stresses and deformation are induced in the piston made of aluminium and hence it is least suggestable.
5. It is observed from thermal analysis that heat flux reduces in the piston made of ZAMAK 3 alloy compared to Al and Al 4032.
6. The piston material which induce lower stresses, deformation, strain and reduced heat flux offers high strentgh
7. It is observed that out of three materials used for work, ZAMAK 3 alloy proves to be the best considering in terms of structural and thermal.

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