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THERMAL EFFECT ON TOPOLOGY OPTIMIZED CRANK CASE COVER FOR ADDITIVE MANUFACTURING

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ABSTRACT

This paper introduces a design of crank case cover using topology optimization powered by ANSYS WORKBENCH and to study thermal effects on the optimized model; for addictive manufacturing. Additive manufacturing technique like 3D printing can fabricate three-dimensional assets directly from CAD Drawings created in any software on a successive level. It could reduce the number of processes parts as well as the material loss for a large extend. The goal is to obtain an optimal design using computer simulation, in order to reduce a 30 percentage of total weight of the component hence achieving a performance improvement and a reduction of material wastage; without any compromise of structural and thermal strength.

Keywords: crank case cover, topology optimization, additive manufacturing, structural analysis, temperature effect.

INTRODUCTION

In the most modern production technics, Additive Manufacturing also known as 3D printing is the leading. This technology incorporates modern computer software packages like CAD-CAE to form a successive layer by layer addition of material and obtaining most complex products and parts with micron level accuracy and reduced material wastage. The automobile and aerospace industries all over Europe has been adopting this technology from the past few years. The famous sports car manufacture koenigsegg [1] the aviation giant Airbus [2] adopted this technology in their product development gaining a less part more production and better profit.

A crank case cover is a crucial part of the engine which carries most of the load from crank shaft and thermal loads. This paper discusses a method to reduce the weight of the crankcase cover without compromising the structural rigidity under various loads using topology optimization. It is complex to manufacture using conventional methods of casting and machining but the Additive manufacturing could save time effort and produce much accuracy.

Modern CAE packages could obtain the stress contours of any desired part or product. By the advanced computing power, it is possible to obtain optimized design. This paper describes the topology optimization of a crank case cover for a single cylinder IC engine. In order to obtain the result of incorporating additive manufacturing of any shape regardless of its complexity by reducing 30 percentage mass of initial design domain. The initial modelling is done using CATIA V5 R20 and later modified using ANSYS Space Claim, with the aid of ANSYS Topology Optimization. The initial design considers structural loads later it is verified for the performance under thermal loading.

DESIGN ASPECTS

Here in this paper the main concentration is on crank case cover; the geometry and the requirements of the crank case cover solely depends upon the engine. The specification of the engine (currently under development) is tabulated in Table-1.

a) Engine specification

Table-1. Specification of 4 stroke engine.

Specific	Description
Engine Type	Air-cooled 4-stroke Single cylinder
Bore x Stroke	68 X 45 mm
Displacement	163 cm3
Net Power Output*	4.8 HP (3.6 kW) @ 3,600 rpm
Net Torque	7.6 lb-ft (10.3 Nm) @ 2,500 rpm
Compression Ratio	9.0 : 1
Lamp/Charge coil options	25W, 50W / 1A, 3A, 7A
Carburetor	Butterfly
Starting System	Recoil Starter
Lubrication System	Splash
Oil Capacity	0.61 US qt. (0.58 L)
Dry Weight	33 lbs. (15.1 kg)

b) Crank case cover: Material

Reduced weight and high structural rigidity is the key factors required for all components of an IC engine. For this purpose, the industries widely use aluminium alloys. Here the material that's been selected is aluminium 6061 T-6 a precipitation –hardened tempered alloy. The machinability, weld ability, corrosion resistance made this material ideal for this engine parts. The aluminium 6061 T-6 having the material constituents scheduled in Table-2.

Table-2. Aluminium 6061 composition.

Material	% of Weight in total
Silicon	0.4 - 0.8
Iron	0 – 0.7
Copper	0.15-0.4
Manganese	0-0.15
Magnesium	0.8-1.2
Chromium	0.04-0.35
Zinc	0 - 0.25
Titanium	0 – 0.15
Others	0.05 -0.15
Aluminum	95.85-98.56

c) Material properties

The physical properties as discussed in Table-3 [3].

Table-3. Material properties.

Specific	Description
Density	2.70 g/cm^3 (169 lb/ft^3)
Elastic (Young's, Tensile) Modulus	69 GPa (10.0 x 10^6 psi)
Electrical Conductivity	43 % IACS
Elongation at Break	15 %
Fatigue Strength	97 MPa (14 x 10^3 psi)
Melting Onset (Solidus)	582 °C (1080 °F)
Shear Modulus	26 GPa (3.8 10^6 psi)
Shear Strength	207 MPa (30 x 10^3 psi)
Specific Heat Capacity	900 J/kg-K
Strength to Weight Ratio	115 kN-m/kg
Tensile Strength: Ultimate (UTS)	310 MPa (45 x 10^3 psi)
Tensile Strength: Yield (Proof)	270 MPa (39 x 10^3 psi)
Thermal Conductivity	170 W/m-K
Thermal Diffusivity	70
Thermal Expansion	23.4 µm/m-K

Crank case cover

Crank case cover is a removable part in the crank case, which acts as a service hatch that gives access to the crank shaft, camshaft and connecting rod assembly. It shields the lubrication oil from spilling, and it provides ports for removing and refilling engine oil.

It is bolted to the crank case; here in this case 6 bolts of M8 standard is used along with a rubber lining to provide insulation from leaking oil and avoiding foreign particles inside.

The main loads acting on the crankcase cover are the bearing loads from shafts rotations, a load due to thermal expansion from a temperature of 180^0c, negligible pressure load due to the engine oil.

METHODOLOGY

While designing a crank case to consider the shear flow as well as the shear center are feasible. Function of the crank case is to provide support for all the moving components in the engine in order to achieve this purpose the crank case need to be designed such a way that it will carry all the vibrations and will not obstruct the motion of crank shaft and cam shaft. Based upon the design of crankcase it will achieve the crank case cover geometry
.

a) Initial modelling

Basic shape of crankcase cover would be extracted from the crankcase and provisions are need to be support the crank shaft, cam shaft and bolt mountings. Modelling is done using Dassault Systems CATIA V5R20. Oil provision holes are not considered initially. The initial design is shown in the figure1a, b.

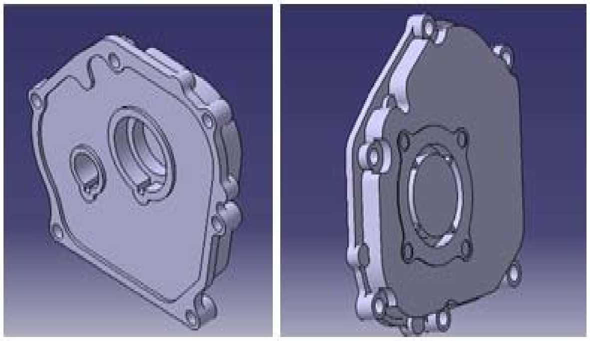


Figure-1. a, b Crank case cover modeled in CATIA.

b) Static structural analysis

Maximum pressure of 22 bar generated inside the cylinder due to the burning of air-fuel mixture. This pressure will be transmitted in to crankshaft via piston and connecting rod. There are chances of reduction in this load during transmission. To ensure efficient design; two times of the actual load is applied on the crank shaft support as well as cam shaft support [4]. The actual load is considered to be 2.2 Mega Pascal for the initial analysis; effect of the temperature is not considered. The result from static structure analysis obtains contours of high stress and low stress regions as shown in Figures-2, 3 ,4.

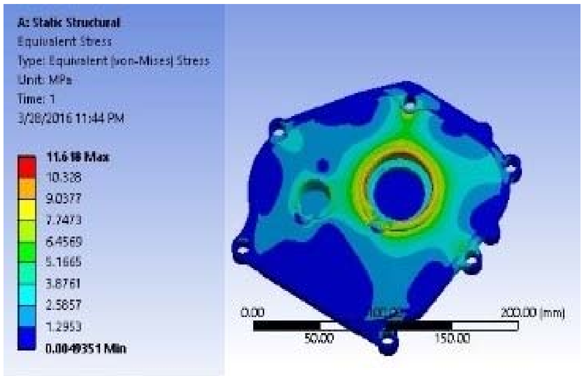


Figure-2. Result of equivalent (Von-Mises) stress.

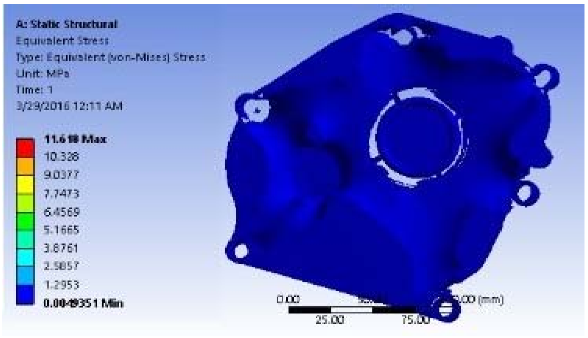


Figure-3. Result of equivalent (Von-Mises) stress.

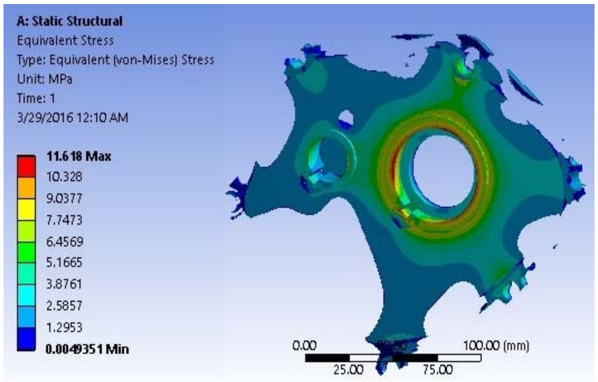


Figure-4. Result of equivalent (Von-Mises) stress.

c) Topology optimization

Topology optimization is to find an optimal structure using numerical methods to optimize the material layout with in the chosen design space [5]. Topology optimization uses Finite Element Analysis incorporation with optimization techniques based on the Methods of Moving Asymptotes (MMA), Genetic Algorithms (GA), Optimality Criteria (OC) method, level sets, and topological derivatives [6].

In figure shows the design region and region to exclude in the initially modelled crank case cover using Topology Optimization in ANSYS V17.0. The Manufacturing feasibility constrains is specified minimum size and percentage weight reduction.

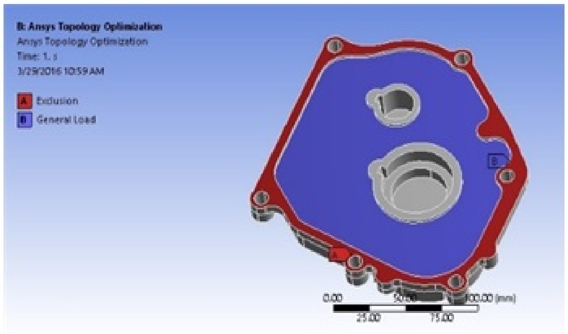


Figure-5. Load constraints given on crankcase cover.

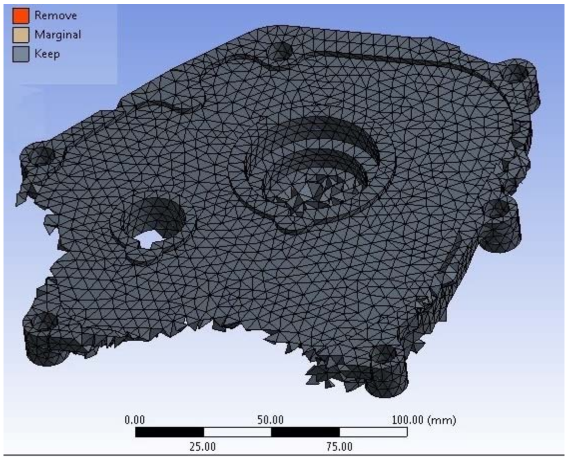


Figure-6. Results for materials to keep.

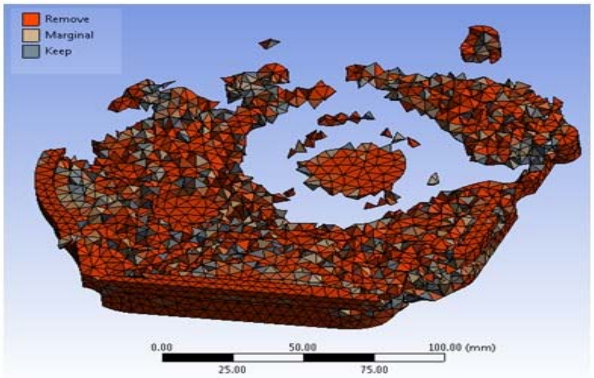
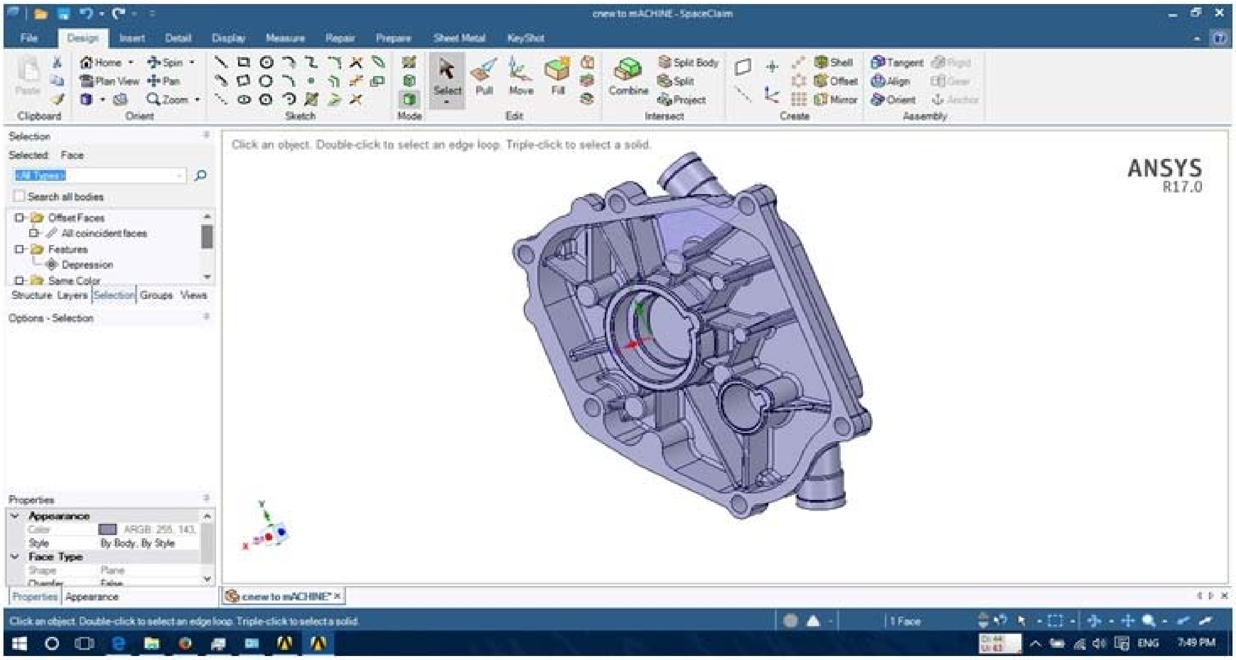


Figure-7. Result for topology optimization.

Re-modeling

In Figure-7 shows irregular geometry of elements that are need to be kept. The obtained geometry cannot be manufactured using any methods for the full extent. By using topology optimization, it gets a Stereo Lithography file good format for 3D printing, but cannot be edited using general CAD software's for this purpose; ANSYS Space Claim is used [7].

In figure shows the re-modeled crank case cover using Space Claim by addition of sufficient bosses, ribs. Provisions for engine oil inlet are provided later-on in this design. Geometrical adjustments are made on the ribs to provide a smooth passage for the oil inlet.



Click an object. Double-click to select an edge loop. Triple-click to select a solid.

Selected: Face

Figure-8. Re-modelled crankcase cover.

Verification of structural stability

The equivalent stresses are computed so that the component posses sufficient factor of safty according to the industry standards using the same loads specified in title 4.1.

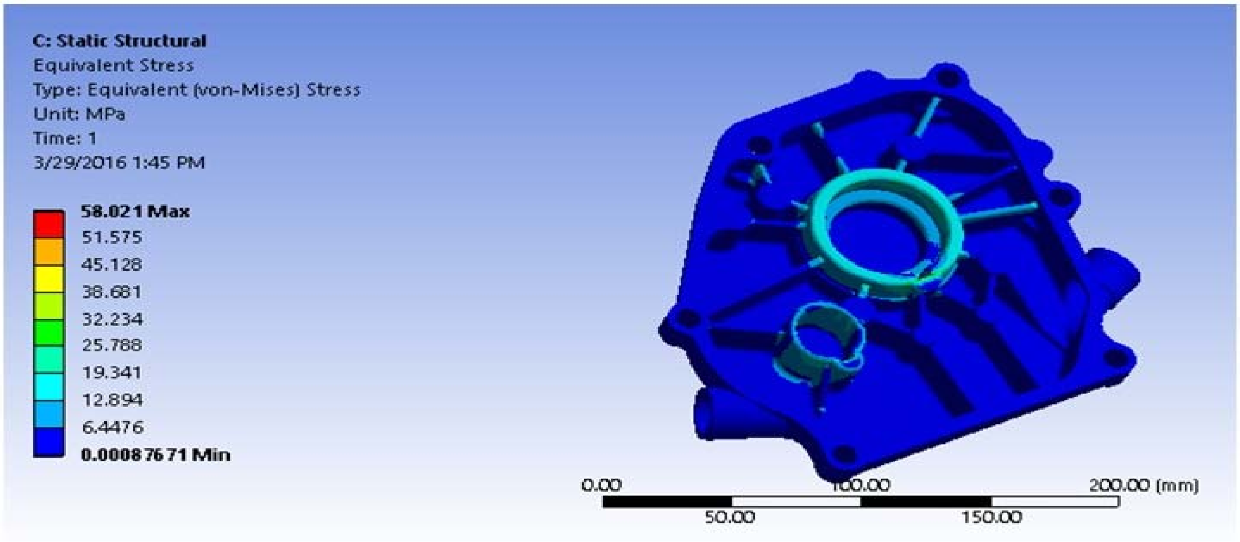


Figure-9 Result of equivalent (Von-Mises) stress.

Thermal loads

The main source of the thermal load is a heat conducted from combustion chamber to the rest of the engine parts. This temperature can raise up to 350 ^{0}C [8]. Engine oil circulated inside the crankcase and the fins provides convection so that it could avoid thermal stress for an extent. The atmospheric temperature 30 ^{0}C, crankcase temperature measured as 180 ^{0}C and Aluminium has a coefficient of thermal expansion (CTE) equivalent to 23.4 µm/m-K. The temperature effect creates noticeable value of stress which need to be considered so that account of thermal analysis followed by a structural analysis is carried out (Figure-10, 11, 12).

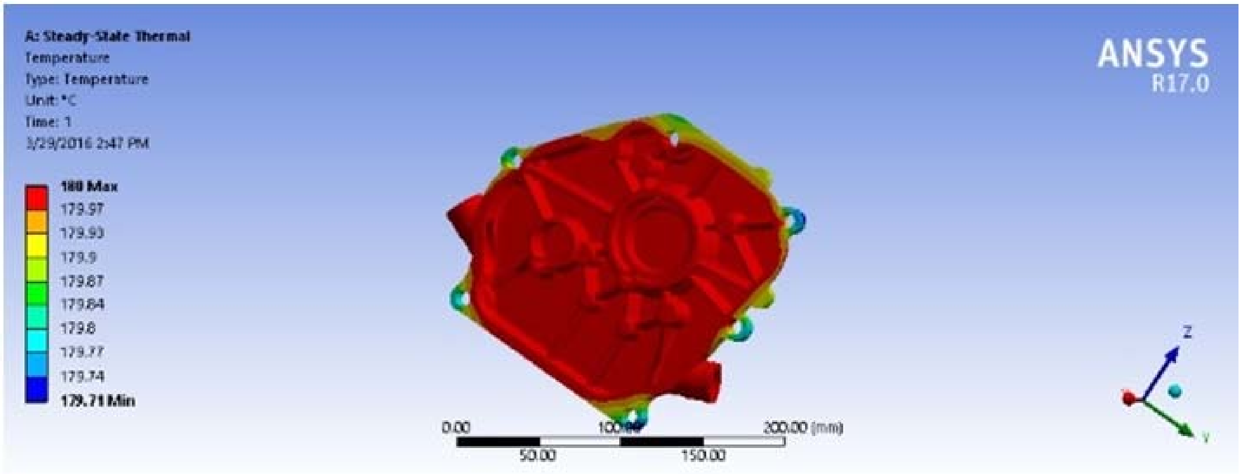


Figure-10. Result of steady-state thermal analysis.

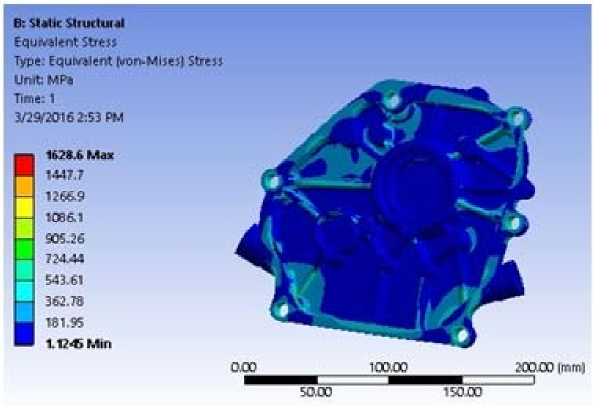


Figure-11. Result of equivalent (Von-Mises) stress.

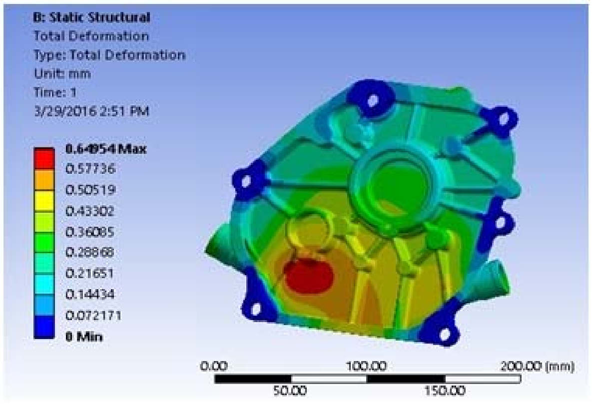


Figure-12. Result of total deformation.

RESULT AND DISCUSSIONS

The initial geometry has volume: 4.909e+5mm^3, Mass: 1.3598kg is obtained factor of safety 18. The re-modelling of the crank case cover has carried out using Topology Optimization. Is obtained volume: 2.2462e+5mm^3, Mass: 0.622224 kg and factor of safety 4.8. The industry requirement is between 3 and 5.

An additional consideration is required by doing thermal analysis revealed a large stress formation at the fastening areas.

CONCLUSIONS

The topology optimization in Crank case cover reduced a net mass of 0.737kg from the initial design. This could lead to a better performance of the engine. While achieving this reduction in mass, necessary precaution is to be taken to ensure the factor of safety is still in the industry standards. The advanced and High Performance Computing with ANSYS Topology Optimization formed a better result than the conceptual designs.

There are two problems to be discussed and solutions need to be advised. The first one high localized stress at the fastenings, by increasing area by providing fillets or provide much length for the fastening support this problem can be solved. The second problem is during manufacturing; conventional manufacturing methods like Casting, Molding, and Forming are not feasible with the design. Meanwhile Additive Manufacturing will give a better result. The goal of the paper is to obtain a 30 percentage in weight reduction of the initial design domain; but the result was a promising 50 percentage in weight reduction.

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