Mechanical Analysis of Downsized Automobile Piston through Simulation

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Abstract

Engine downsizing technology benefits the environment in terms of emission gases and also reduces the usage of fuel in automobiles. Reducing the number of pistons and or their dimensions is among the most suitable techniques for engine downsizing. However, reducing the size of the pistons will cause another issue with withstanding the applied forces generated due to combustion gases during combustion. Therefore, in this research work, the automobile piston was analyzed through simulation using ANSYSv17.2 after a 10% stroke reduction in its dimension. Further, to advance the novelty of this research work; 02-different automobile piston shapes: and hollow and toroidal combustion chambers (HCC & TCC) were reduced for investigating mechanical analysis. For mechanical analysis: maximum principal stresses, Von-Misses stresses, and total deformation before and after downsizing were analyzed. The results revealed that the maximum principal stresses, Von-Misses stresses, and total deformation were increased by 42%, 33.5%, 41.4%, 26.7%, 14.1%, and 8.2% after downsizing the HCC and TCC pistons respectively. Additionally, TCC offered better resistance to applied forces as compared to HCC. However, the increased values were within the maximum ultimate stress of the material, and it can be concluded that the 10% by stroke downsizing is under safe mode.

Keywords—Automobile Piston; Downsize Engine Piston; Mechanical Analysis; ANSYS v17.2; Aluminum Alloy

1 Introduction

Due to harsh emission of fuel protection strategies useful for present internal combustion (IC) engines, the world is turning towards the low emissions of carbon, nitrogen oxide, and hydrocarbons [1]. The emission of IC engine gases is considered as major concern in modern IC engine designs [2]. To handle these issues numerous techniques such as using turbochargers, superchargers, twin-charging, direct fuel injection (DI), advanced exhaust gas recirculation (EGR), and variable valve timing (VVT) have been developed for IC engines [3].

Turbocharging and supercharging category of downsize has become the most successful among the other categories. The main reason behind it is that it does not require any additional supplementary parts, and only in it; either the number of pistons reduced and or their size (swept volume). Whereas, the turbocharging devices maintained the output power at the bar even after a reduction in the number of parts and or their size [4]. However, reducing the size of the automobile piston could lead to other problems like large amounts of mechanical stresses due to combustion gases and premature failure of the piston [5].

The automobile piston is considered the main part of the IC engine, which supports the combustion of gases during the combustion process [6]. Heavy amounts of gas forces are generated during the combustion process, which directly acts on the face of the automobile piston [7]. Therefore, the automobile piston material must be enough strengthened to withstand these gas forces [8]. On the other side, the shape of the piston is also prime important to support the combustion process [9]-[10]. Generally, three different piston shapes such as hemispherical combustion chamber (HCC), toroidal combustion chamber (TCC) and shallow-depth combustion chamber (SCC) have been used for obtaining better performance and output during the combustion process [11]-[12]. Though numerous studies have been conducted to investigate

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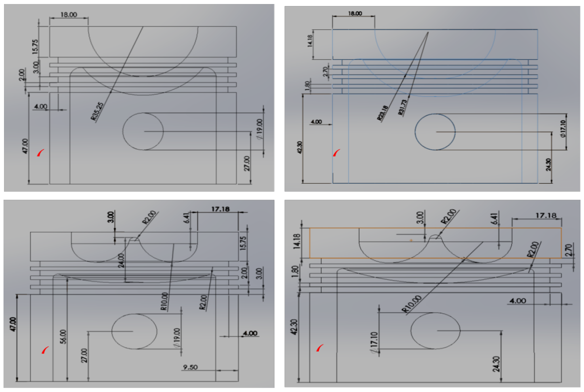

Fig. 1: 2-D drawing of HCC (a) before downsizing and (b) after downsizing, and of TCC (c) before and (d) after downsizing

the performance of all these piston shapes [13-15], however, no study has been conducted to investigate the mechanical analysis of those. Even if there are studies on the mechanical analysis of pistons through simulation; the research gap in the mechanical analysis of those piston shapes through downsizing is still not done. Therefore, this research work investigates the mechanical analysis of HCC and TCC piston shapes downsized at 10% by swept volume using ANSYS v17.2. Further, the mechanical analysis of those pistons before downsizing was also carried out for analysis and comparison purposes.

2 MATERIALS AND METHODOLOGY

The two different shapes of the piston hollow combustion chamber (HCC) and toroidal combustion chamber (TCC) were used for the mechanical (static structural) analysis through ANSYS v17.2. The part modeling of both piston shapes was carried out in Solid Works workbench v16. The developed part modeling of both piston shapes was extracted to ANSYS v17.2 software for mechanical analysis. The 2-dimensional drawing of both piston shapes before and after downsizing is shown in Figure 1. Further, meshing was generated for HCC and TCC before and after downsizing as shown in Figure 2.

AA6081-T6 aluminum alloy was used for mechanical analysis of the HCC and TCC piston shapes. AA6081-T6 aluminum alloy is categorized in the AA6000 series, and its major composition consists of Al (96.3-98.6%), magnesium (0.6-1%), silicon (0.7-1.1%), manganese (0.1-0.45%) along with traces of copper, iron, and titanium. Their mechanical properties and meshing data are depicted in Tables 1 and 2 respectively. This kind of piston aluminum alloy is

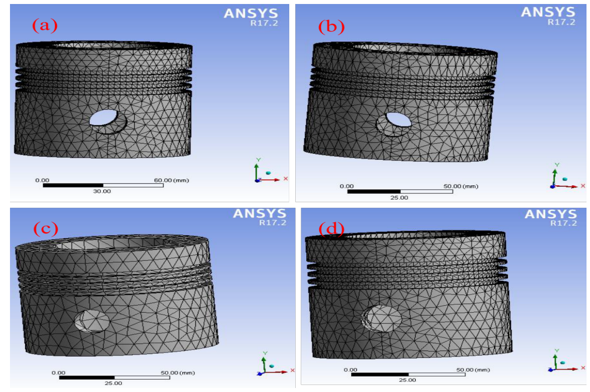

Fig. 2: Meshing of HCC (a) before downsizing and (b) after downsizing, and of TCC (c) before and (d) after downsizing.

TABLE 1: Mechanical Properties of AA6081-T6 utilized for mechanical analysis

Density (g/cm^3)	2.70
Tensile Yield strength (MPa)	280
Tensile Ultimate strength (MPa)	310
Young's Modulus (GPa)	71
Co-efficient of thermal expansion	2.3E^{-05}
Poisson's Ratio	0.33

produced through casting and forging. Further, for attaining fracture toughness and to improve mechanical properties of AA6082-T6 aluminum alloy multistage heat treatment carried on it.

3 RESULTS AND DISCUSSION

Three different results such as maximum principal stresses, Von-Mises stresses and total deformation of HCC and TCC pistons before and after downsizing were analyzed through simulation. A comparative analysis of both pistons was also discussed in the end of the results section.

3.1 Maximum principal stress of HCC before and after downsizing

Figures 3 (a) and (b) show the maximum principal stresses of the HCC piston before and after downsizing respectively. The value of the maximum principal

TABLE 2: Meshing Data for the Piston Analysis

Meshing	HCC Downsizing		TCC Downsizing	
	Before	After	Before	After
Nodes	25600	23619	20844	18635
Elements	14028	12632	12670	10814

stress of HCC before the downsizing was obtained as 126.7MPa. The point location of the maximum principal stresses is at the upper face of the HCC piston. Whereas, after downsizing, the value of maximum principal stress was obtained as 216.9MPa at the same location of the HCC piston. Therefore, it can be observed that the value of maximum principal stresses after downsizing increased by about 42% as compared to HCC piston before downsizing. Thus it can be evident that by reducing the size of the piston, the value of maximum principal stresses will be increased. However, the maximum value of maximum principal stresses for HCC piston material is in safe condition. The same trends of results were also obtained by Sroka [4], where an increment of 42% was achieved after downsizing the piston. Further, Ahmed et al., [5] also concluded that the stress value will be increased after reducing the dimension of the piston.

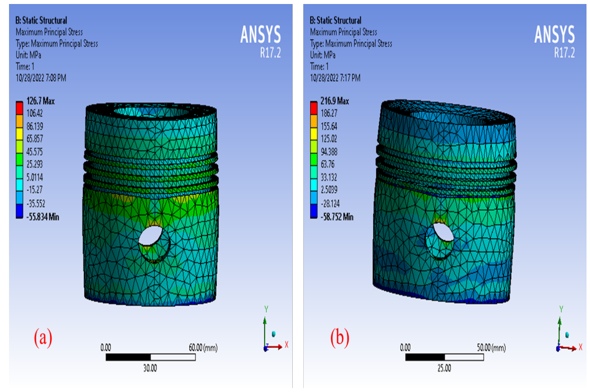

Fig. 3: Maximum Principal Stress of HCC (a) before and (b) after downsizing

3.2 Von-Mises stress of HCC before downsizing

Figure 4 (a) and (b) show the Von-Misses stresses of the HCC piston before and after downsizing it respectively. The results of Von-Misses stress of HCC before the downsizing obtained 222.78 MPa, and 334.93 MPa after downsizing of the piston. However, the maximum value of Von-Misses stresses is still under the maximum value of UTS of the material. Further, the location of the maximum value of the Von-Mises stresses before and after downsizing is the piston crown. It is mainly due to the direct-acting of the applied forces applied on the crown of the piston. Further, the forces generated due to the combustion of the gases directly affect the crown of the piston [16]. The maximum percentage increment of 33.5% in Von-Misses stresses occurred in the HCC piston after downsized.

3.3 3.3 Total deformations of HCC before and after downsizing

The results of the total deformation of HCC piston before and after downsizing are shown in Figure 5 (a) and (b) respectively. The results for total deformation of HCC before the downsizing were obtained as 0.098155 mm, whereas after downsizing is 0.16753 mm. The maximum percentage increment of 41.4% in total deformation was obtained after downsizing the HCC piston shape. The obtained results depicted that the total deformation increased after downsizing the HCC piston. The same trends of results were also obtained by Sroka [4]. Also, Ahmed et al., concluded that reducing the size of the piston will increase its deformation of it [5]. Further, the major point location of the maximum value of total deformation is the piston crown of the HCC piston. Meanwhile, the location of the total deformation before downsizing reached approximately the piston ring area of the HCC piston.

3.4 Maximum principal stress of TCC before and after downsizing

The results of the maximum principal stress of TCC before and after downsizing are shown in Figure 6 (a) and (b) respectively. The obtained results of maximum principal stress for the TCC piston before downsizing is 123.11 MPa, whereas, it is 167.89 MPa after downsizing it. The obtained results showed that the maximum percentage increment of 26.7% was achieved after downsizing the TCC piston. The location of the maximum principal stress for TCC before and after downsizing is the piston crown. Further, the other location of maximum principal stresses for TCC is at the piston pin area. The same trends of results were also obtained by Kiran et al., where the locations of the maximum stresses are at the piston pin area [16]. The reason behind the location of maximum stresses at the piston pin area is that the applied load is transferred toward the connecting rod of the automobile engine. Whereas, the connecting rod is attached to the piston through the piston pin area, and it is considered a fixed area.

3.5 Von-Misses stress of TCC before downsizing

The results of Von-Misses stresses of TCC before and after downsizing are shown in Figures 7 (a) and (b) respectively. The maximum values of Von-Misses stress as 197.91 MPa and 230.38 MPa were obtained for the TCC piston before and after downsizing respectively. However, the maximum value in both cases is below the maximum UTS of the material. The obtained

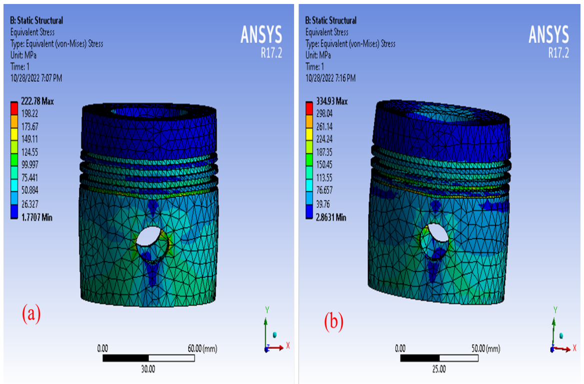

Fig. 4: Von-Misses stresses of HCC (a) before and (b) after downsizing

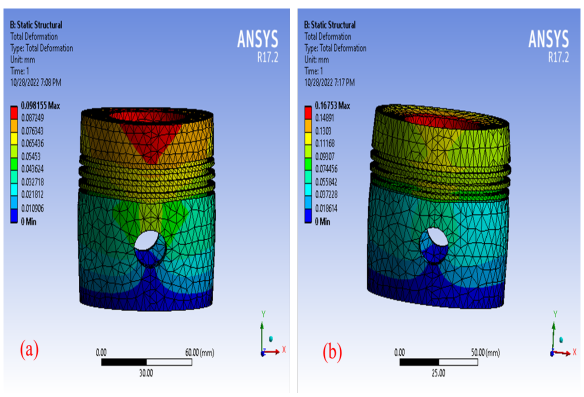

Fig. 5: Total Deformation of HCC (a) before and (b) after downsizing

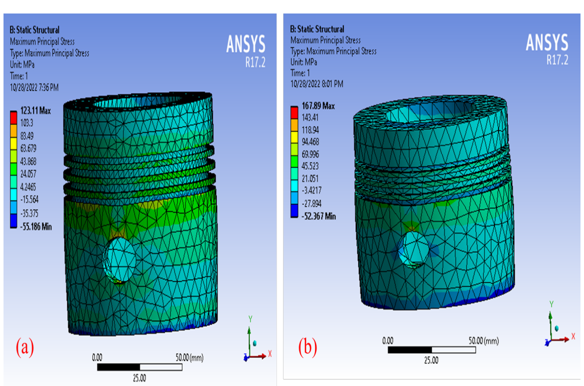

Fig. 6: Maximum Principal stresses of TCC (a) before and (b) after downsizing

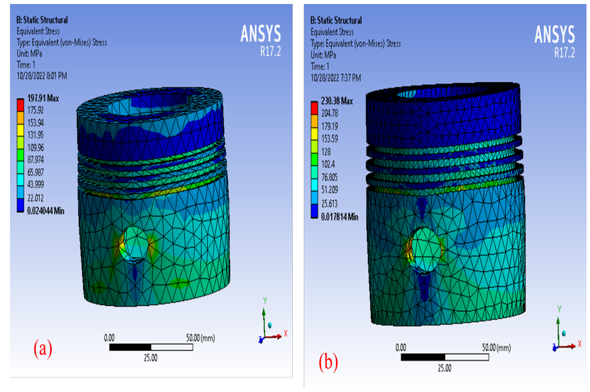

Fig. 7: Von-Misses stresses of TCC (a) before and (b) after downsizing

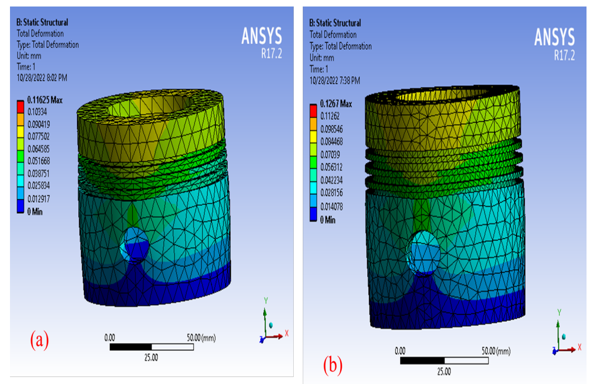

Fig. 8: Total deformation of TCC (a) before and (b) after downsizing

results depicted that the maximum percentage increment of 14.1% occurred after dowsing the TCC piston. Further, the maximum value of Von-Misses stresses is produced at the piston crown and piston pin area. It is mainly because the combustion gas forces produced in light of combustion are directly affecting the piston crown area of the piston. Further, these forces are transferred from the piston crown to the piston pin, and these forces produce deformation in the piston pin location.

3.6 Total deformation of TCC before downsizing

Figures 8 (a) and (b) showed the results of total deformation of TCC before and after downsizing respectively. The maximum value of total deformation for TCC was achieved as 0.11625 mm and 0.1267 mm before and after downsizing respectively at the piston crown. Further, the maximum percentage increment of 8.2% was achieved for TCC after downsizing the piston.

TABLE 3: Mechanical Properties before and after downsizing 10% by stroke

Mechanical Properties	Before Downsizing	After Downsizing
HCC Piston		
Maximum Principal Stress, MPa	126.7	**216.9**
Von-Mises Stress, MPa	222.78	**334.94**
Total Deformation, mm	0.098155	**0.16753**
TCC Piston		
Maximum Principal Stress, MPa	123.11	**167.89**
Von-Mises Stress, MPa	197.91	**230.38**
Total Deformation, mm	0.11625	**0.1267**

3.7 Comparison of results of HCC & TCC before and after downsizing

The comparative analysis of results for HCC & TCC piston shapes before and after downsizing. All the calculated results such as maximum values of maximum principal stress, Von-Misses stress, and total deformation of the HCC and TCC before and after downsizing as shown in Table 3 are discussed here. The obtained results revealed that the maximum principal stress, Von-Misses stress, and total deformation were increased after downsizing 10% of both piston shapes (HCC and TCC). It is well-known fact that reducing the size of the part will increase the stresses acted on it due to applied forces. It is mainly because of the reduction in resistance offered by the part to the applied forces on it. Further, 42%, 33.5%, and 41.4% increment in maximum principal stresses, Von-Misses stresses and total deformation respectively was found for HCC after downsizing it. Whereas, for TCC after downsizing, the maximum principal stresses, Von-Misses stresses and total deformation increased 26.7%, 14.1%, and 8.2% respectively. Found in HCC pistons that are 216.9MPa, 334.94MPa and 0.16753mm respectively.

4 CONCLUSION

Research work on downsizing is the latest and emerging in numerous developed countries. The main benefit of downsizing is to reduce the air pollution produced due to the combustion of gases during the combustion process in IC engines. The other benefit of downsizing is the reduction in the quantity of fuel for combustion, and by doing so, less quantity will generate less amount of air pollution. Nonetheless, the concept of downsizing is to reduce either the number of cylinders or reduce the size of the combustion chamber (mainly the piston).

The concept of engine downsizing and its effect on the mechanical load of the piston is provided. Maximum principal stress, Von-Misses stress, and total deformation were analyzed under the 25 MPa pressure applied at the head of the piston. The downsizing of the piston increased these parameters. However, all changes are applicable because of the strength of the material of the piston. This indicated that the method of downsizing can be brought to the tested engine. Keeping in view all the above-achieved simulation results of HCC and TCC in ANSYS v17.2, it can be concluded that the 10% of downsizing through stroke of the engine piston can be applicable even after maximum principal stress, Von-Misses stress, and total deformation increased. The increase of these parameters does not affect the performance of the engine because of the attachment and performance of the turbocharger in a downsized engine. The turbochargers boosted the supply, utilized the exhaust temperature, and maintained the engine power at par.

For HCC, the maximum principal stress before downsizing was 126.7 MPa and after downsizing it was increased to 216.9 MPa. The recorded increment is observed inside the wrist pin. The Von-Mises stress before downsizing was found 222.78 MPa and after downsizing it was increased to 334 MPa. The total deformation before downsizing was noticed at 0.098155 MPa and after downsizing it was increased to 0.16753 MPa.

For TCC, the maximum principal stress before downsizing was equal to 123.11 MPa and after downsizing it was increased to 167.89 MPa, the recorded increment is observed at the piston crown and piston pin. The Von-Mises stress before downsizing was found 197.91 MPa and after downsizing it was increased to 230.38 MPa. The total deformation before downsizing was noticed at 0.11625 MPa and after downsizing it was increased to 0.1267 MPa.

5 FUTURE RECOMMENDATIONS

The field of engineering is advancing to small weights and reducing the dimensions of the components while maintaining the output or even increasing it. There are many techniques to reach these goals, downsizing and material selection are the two of them. Mainly aluminum alloys are preferred for the manufacturing of pistons because aluminum alloys are light in weight and have good strength along with low coefficient of thermal expansion.

To continue further research work in the field of material application in downsizing engines and other related fields, it is recommended to employ other grades of aluminum alloys especially related to automobile piston alloys such as AA2024, AA2618, AA4032, and AA7075.

Also, for finding the mechanical stresses for the piston in a downsized engine, it is recommended to use other downsizing percentages from 15% to 40% by swept volume.

Other combustion chamber shapes such as flat shape, and shallow combustion chambers may also be investigated for downsizing either by the diameter of swept of the piston.

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