



# Mechanical And Thermal Issues In Downsize Engine: A Review

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## Abstract

This work is highlighting the previous research work on the mechanical and thermal issues in the Downsize Engine. By using downsize engine technology, the consumption of fuel and emission decreased by reducing geometrical dimensions of combustion chamber parts and thermal and mechanical efficiencies increased by increasing the power output bywith the help pg using turbochargers. Using turbochargers, a super knock could result from the pre-ignition and induces severe oscillation and leads to the thermal and mechanical stresses on account of diminished mass and geometrical aspects of the various parts employed in the combustion chamber (CC). The increment in thermal and mechanical stresses may damage the main part(s) (piston) of the combustion chamber. In focusing the above facts; the shape design and the best material is the right choice for the better combustion and long life of the CC parts (piston) in downsizing engine respectively.

**Keywords:** Downsize Engine, Pre-ignition, Mechanical & Thermal Issues, Combustion Chamber Part.

## 1. Introduction

In the advancement of internal combustion (IC) engine developments, many new combustion technologies introduced. One of the patterns for advancement of IC engine is downsizing, which in its final form prompts reduction of fuel consumption by decreasing volume of cylinder and impediment of carbon dioxide percentage in the exhaust gasses.

The undeniable impact of diminishing the volume of a cylinder is to decrease the dimensions of the different parts, e.g. piston with rings and pin, connecting rod, crankshaft, engine block and so forth. Changes of geometric dimensions also affect the change in mass of each element and consequently the whole engine. Expected weight reduction will be a benefit in considering downsizing techniques as another significant development trend in automotive applications associated with a reduction in the weight of the complete vehicle called “light weight vehicle”. The relationship of downsizing with IC engine is the reduction of swept volume by keeping or increasing engine power. The well-known relationship to understand the geometries for downsizing engine is given by [1].

$$W_d = 1 - AB^2 \tag{1}$$

Where:

$$A = \frac{S_d}{S}$$

$$B = \frac{D_d}{D}$$

The above equation can also be defines in geometrical perspective as:

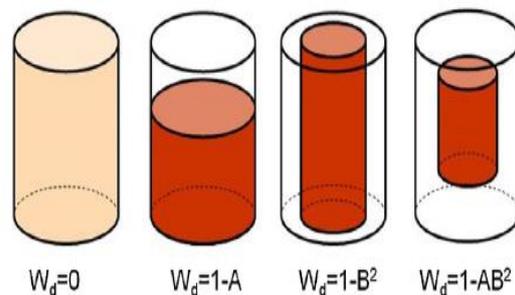


Fig. 1 Variants of downsizing and corresponding ratios [1]

The other major benefit of downsize engine is the reduction of CO<sub>2</sub> through exhaust gases and this can be intended through using the equation:

$$CO_2 = D \times E \times F \tag{2}$$

Where:

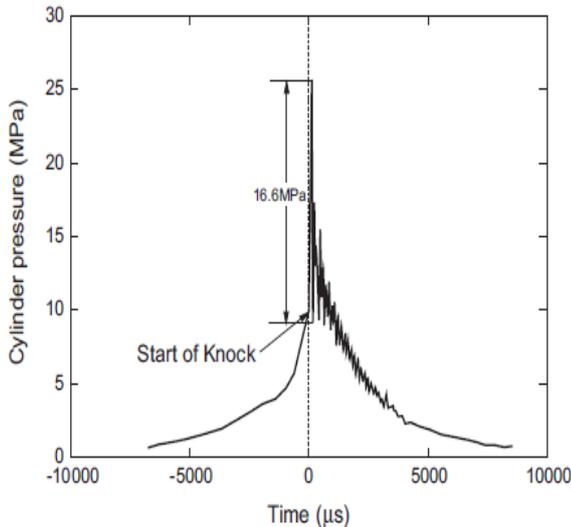
D = Vehicle Mileage  
E = Energy per Kilometer  
F = CO<sub>2</sub> per energy

From this equation, the CO<sub>2</sub> can be reduced either by “E” the energy per Kilometer (fuel consumption) or by the “F” production of CO<sub>2</sub> per energy [2]. These two parameters are the main bases and can be achieved through using new fuels or by using downsize engine technology.

The present-day research work witnessing and demonstrating the decrement in the energy consumption and CO<sub>2</sub> concentration in the downsizing of engine. This is all because of the reduction in the shape and size of the CC parts. But on the other side, due to such reduction leads to many technical hitches in downsizing the engine such as mechanical loadings, high values of stresses in the combustion chamber, distressing the thermal loading (Mean

effective pressure), improper pressure & heat release and many more if not properly designed. Due to these problems an abnormal combustion spectacle (pre-ignition) resulted out supplemented by engine downsizing. Such kind of pre-ignition is dissimilar to the common pre-ignition which is produced by glowing deposits in the combustion chamber or by local hot spots caused by improper and inadequate cooling of surfaces [3]. This pre-ignition resulted super knock which is more dangerous than that of ordinary knock often take place. In [4-11] work, the maximum cylinder pressure reached up to 16.6 MPa (Fig. 2) due to super knock.

Fig. 2 The pressure curve in super knocks [8]



The super knock categorized by pressure amplitudes which are considerably greater than that of ordinary knock. Since the super knock is produced by the pre-ignition and the pre-ignition in engine downsizing is challenging to be removed. Moreover super-knock produced stochastically and cannot be controllable in the same way as ordinary knock [12].

The focus of this review is to understand the knocking issues accompanied with pre-ignition and the mechanical loadings in the highly boosted (downsize) engines. On the basis of literature reviewed in this paper, various downsize engine technologies are also discussed. Additionally, the latest development in the downsize engine technology in Malaysia is discussed. In the last, on literature review basis, the authors found some literature gaps and discussed in this paper.

## 2. Relationship between super-knock and pre-ignition

There are mainly 02-major benefits of the downsize engine: 1) reduction in the fuel consumption and 2) reduction in CO<sub>2</sub>. The first benefit achieved by reduction of the geometrical aspects of the CC parts. This leads to mechanical and thermal problems. In thermal problems: mainly is the improper combustion. Fig. 5 shows and summarized that the improper combustion generated by means of downsize engine. Additionally focusing the relationships among pre-ignition, conventional knock and super-knock in downsize engines: combustion can be partitioned into normal combustion (non-knock) and engines knock as per the pressure amplitudes. Further, engine knock is classified into two categories: conventional knock and super-knock. End-gas deflagration and end-gas detonation are the two kinds of super-knock. But however; pre-ignition is the origin of abnormal combustion and can lead to end-gas detonation (super-knock), end-gas deflagration (super-knock, heavy-knock, slight-knock), and turbulent flame propagation (non knock). Automobile organizations and engine research societies have broadly revealed super-knock and pre ignition problems in downsized engines and inspected this

phenomenon in recent years. Among them, many researchers concluded super-knock as pre-ignition.

Though pre-ignition is required for the occurrence of super-knock but it does not always lead to engine knock. Even considerably progressing spark timing can only simulate pre-ignition, not the super knock. But always ordinary knock takes place, while super-knock takes place randomly [8].

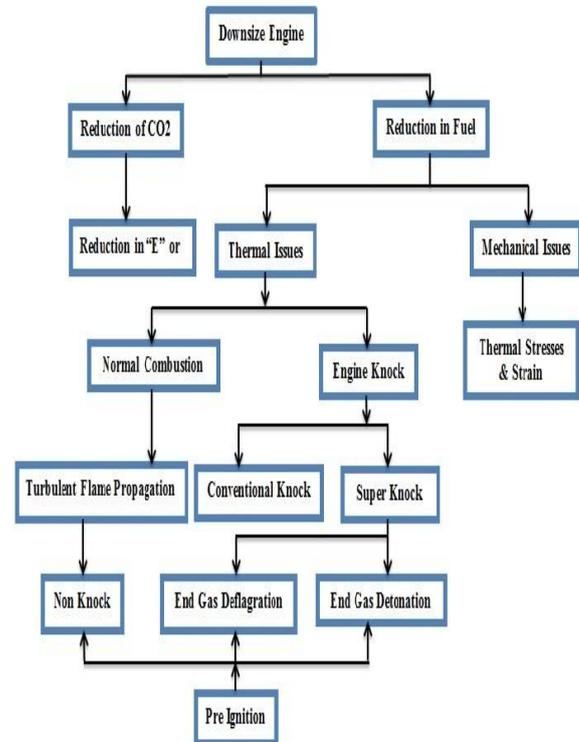


Fig. 3 Classification of knocking combustion in high boosted gasoline engines

## 3. Mechanical and Thermal Issues in Downsize Engine

For a bigger effect in reducing fuel consumption and decreasing carbon dioxide in the exhaust, recently strong downsizing is entered. Downsizing of IC Engine means simultaneous reducing the displaced volume (generally by decreasing the quantity of cylinders) and improving the Indicated Mean Pressure (IMEP) by means of turbocharging [13-14]. This allows the conservation of power and torque execution while reducing the engine size. [16]. On the other side, many scholars attributed that downsize engine still have many areas to research and develop which not only improve the thermal and mechanical efficiency but also pace to the better mechanical and thermal stresses generated inside the combustion chamber when only geometric dimensions reduced in downsized engine. As [1] research results show the increment by 41.7% in the translation vector displacement in downsized engine piston then the normal one. The values of Huber-Mises stresses increased by 35.9% and the highest stress values were recorded near the second sealing ring. High stresses occur in the crown of the piston, which directly operates with combustion gasses. Although the results presented in his research and effects on the mechanical load of piston were showed a level of increment by downsizing, but all changes were acceptable due to the strength of the material of the piston. This means that the technique of downsizing can be introduced to the tested engine. But according to [13] downsizing of the engine, the piston dimensions are also reduced which cause to produce the pressure wave (knock) to such level where mostly piston material damaged and unfortunately most of the time the manufacturer change / replace the piston but not the cause of the problem. In his research, the behavior of

pressure wave can be considered for the explanation of the mechanism: that piston damaged in knock. Knocking is the major hindrance for sourcing high compression ratio to increase the thermal efficiency of gasoline engines. As per [4], it is mostly recognized that engine knock is related with auto ignition in the end gas. In past, the knock was assumed by some scholars to be an outcome of detonation. While [6], research has significantly debarred detonation from the origin of knock due to the lack of considerable indication. The researchers [16] also concluded that detonation was not likely to occurring in IC engines. It is because of the short duration for combustion, cool chamber wall and low heat release rate, which couldn't start detonation propagation.

Since the downsizing and new combustion technologies are introduced, abnormal combustion phenomenon occurred and leads to the high amplitude and high frequency pressure wave (super knock) as shown in figure 6. This also causes the tremendously high peak pressure and the related pressure oscillations advancement in the combustion chamber. Super-knock occurrence can instantly and severely destruct the combustion chamber parts. In a turbocharged gasoline direct injection (GDI) engine, the super-knock damaged the engine and due to it, sparks electrode breakup, exhaust valve melt, and piston ring land broken [9]. In the piston failure research, many researchers recognized the piston failure due to the thermal stress, thermal fatigue and mechanical fatigue [16- 17]. But the consequences of shock waves on the piston failure are rarely researched. Klein [18] has investigated the Rayleigh wave in the piston, which eroded the piston surface at last. In his study, the detonation wave was only highlighted to decrease a resonant Rayleigh wave but the convergence of the shock wave was not discussed which is very essential when downsizing engine is being discussed. As per [19-20], the speed of the pressure wave could reach up to 2000 m/s inside the cylinder, which is similar to the shock wave in the explosion. It can be wondered that the converged shock waves would result overpressure which can easily break the piston. In the last [21], the best design and material for the automobile piston are the main challenges in the downsizing of the engine.

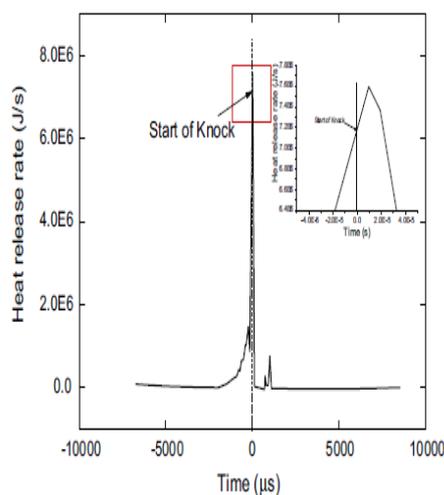


Fig. 4 The Pressure Curve in Super Knock [8].

#### 4. Future Challenges

Pre-ignition is an abnormal combustion phenomenon and commonly resulted in downsize engine in accompanied with some other regular combustion problems. Such pre-ignition is totally different from the common pre-ignition. The main reasons for common pre-ignition are glowing deposits in the CC and local hot spots produced by insufficient cooling of surfaces [3]. However and generally; such reasons are not the base for an abnormal combustion (Pre-Ignition) in downsize engine and cannot be eliminated by customary processes such as changing the inlet temperature, varying the equivalent ratio, changing the octane

number and so on [4] & [5]. These customary processes are compelling for the common pre-ignition, yet they are flopped for the pre-ignition under engine downsizing. Some time, pre-ignition may results a super knock in downsize engine which is more dangerous than regularly occurred normal knock. In such super knock, the amplitude of maximum cylinder pressure reaches up to 16.6 MPa (Fig. 6) and sometime even higher [4–10]. The super knock can be categorized on the basis of pressure amplitudes which are considerably higher than that of common knock [12]. On such base, it should be concluded that the super knock is initiated by the pre-ignition (under engine downsizing) and is hard to be eliminated. Additionally the occurrence of super-knock is stochastically and cannot be controllable in the similar way as normal knock. In the last, the super knock is responsible for mechanical and thermal issues in engine downsizing. Thus the authors are wishing to explore further work on the solution of mechanical & thermal issues in the Downsized Engine.

#### 5. Conclusion

Combustion chamber shape is the auxiliary cause of the piston demolition. Contrasting with the reality piston damaged, it can be reasoned that the region piston broken is always the region shock waves converge. Such rule additionally demonstrates that the shock waves do converge in the combustion chamber and the converged shock waves destruct the piston surface effectively. Thus designing the combustion chamber shape appropriately, the convergence of shock waves can be alleviated or even evaded and the demolition of the piston surface will be relieved.

The shape of the piston is prime important in the design of combustion chamber to control the combustion environment and proper way to exhaust gases to avoid the occurrence of high pressure waves and helps to heat release after combustion. As [3], [22-26] the outcome of IC engine intensely relies on piston displacement, piston combustion area, piston shape and so forth. Discussing the indicated thermal efficiency of IC engine, the piston displacement and the piston area are essential and the piston shape can also alter it. This is the premise, that it is imperative to design this part of combustion engine, especially when design of engine is amended / altered. Additionally present day research work on the downsizing of the engine advantaged not only decrement in CO<sub>2</sub> but also reducing the energy consumption by reducing the swept volume. The reduction of swept volume is the indication of smaller amount of fuel consumption. The two parameters “E” (energy per kilometer) and “F” (CO<sub>2</sub> per energy) are directly proportional to CO<sub>2</sub> production in a way that any parameter either increased or decreased cause to increase or decrease it respectively. The decrement in “E” is only achieved by reducing the geometrical aspects of the CC parts. The reduction in those may cause to generate the mechanical issues. So there are lots of complications in downsizing the engine: high levels of stresses in the combustion chamber, mechanical loadings, affecting the thermal loading (Mean effective pressure) and many more. The only solution of these mechanical and thermal problems is the proper design of the combustion chamber and the selection of best material for CC parts in the downsize engine.

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