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EXPERIMENTAL STUDY ON OTTO ENGINE PERFORMANCE WITH VARIATIONS IN COMPRESSION RATIO AND GASOLINE OCTANE

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Abstract. *This research aims to analyze the effect of compression ratio variation and gasoline octane number on the performance of spark-ignition internal combustion engines. The experimental object was a single-cylinder 124 cc motorcycle engine with an original compression ratio of 9.6:1. The compression ratio was increased to 10.6:1 by reducing the cylinder height by 0.6 mm. Performance testing was carried out using a dynamometer with two types of fuel, RON 88 and RON 92. Octane number 92 was selected based on fuel availability, while octane number 88 was used to evaluate engine performance under an increased compression ratio. A cylinder wall length reduction of 0.6 mm was applied as the maximum allowable limit, beyond which cylinder head modification would be required. The performance parameters evaluated were torque and brake power over an engine speed range of 4000–7000 rpm. The results indicate that increasing the compression ratio from 9.6:1 to 10.6:1 improved engine torque and brake power by approximately 3.8% to 4%. Meanwhile, the use of higher-octane gasoline (RON 92) increased performance by only about 2% to 2.4%, and only when used in the higher compression engine. In contrast, using high-octane fuel in a low-compression engine resulted in reduced performance due to ignition delay. Overall, the optimal performance was achieved when a high compression ratio was paired with high-octane fuel. Therefore, selecting an appropriate octane rating according to the engine compression ratio is essential to achieve optimal combustion efficiency, brake power output, and torque response.*

Keywords: *Performance; Compression Ratio; Fuel Octane*

1 Introduction

Indonesia is a developing country with a large population, reaching 272.2 million people according to the 2021 Indonesian census [1]. There is a high level of human mobility that requires transportation facilities, both public and private. Motorcycles are one type of private transportation, with domestic wholesale sales reaching 5.05 million units in 2021, according to the Indonesian Motorcycle Industry Association (AISI) [2]. A spark-ignition engine is a type of engine that is very commonly used in motorcycles. A spark-ignition engine is constructed to operate on a cycle in which a mixture of gasoline and air is ignited with the help of a spark plug. This differs from a diesel engine, in which the fuel is injected at the end of the compression stroke, causing combustion to occur due to the effect of self-ignition [3]. Over time, gasoline engines have continued to evolve and remain a dynamic benchmark for comparing other types of engines. However, compared to other engine types, gasoline engines have several disadvantages, such as suboptimal efficiency under high loads and limited compression ratios due to the risk of fuel detonation (knocking), which is strongly influenced by the fuel's octane rating [4]. Knocking has the potential to cause various types of damage, including piston head melting, piston ring seizure, and cylinder head gasket leakage [5].

In spark-ignition (SI) internal combustion engines, compression ratio is a fundamental parameter that elevates in-cylinder pressure and temperature, which enhances thermal efficiency but concurrently increases the susceptibility of the unburned end-gas to auto-ignition and consequent knock phenomena under high pressure–temperature conditions. Ignition timing interacts critically with this process: advancing the spark

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increases combustion duration and peak pressures but also raises the energy state of the end-gas, thereby elevating knock tendency, while retarding the timing can suppress knock at the expense of reduced performance and efficiency. Quantitative studies on knock sensitivity consistently rank compression ratio as the dominant contributor to knock tendency, followed by ignition timing and other factors, illustrating their coupled influence on knock onset and intensity in SI engines under heavy load regimes [6], [7]. Although numerous studies have reported ignition timing adjustments for higher-octane fuels, no ignition timing modification was applied in this study in order to isolate the pure effect of increased compression ratio on engine performance [8], [9], [10]. Other engine settings, such as the capacitor discharge ignition, pickup coil position, spark plug and ignition coil remains stock.

The octane number indicates a fuel's ability to resist knocking when it burns inside the cylinder of an internal combustion engine in an air–fuel mixture. A higher-octane number signifies a greater ability of the fuel to withstand higher pressures before ignition. The most common type of octane rating is the Research Octane Number (RON), which is determined by testing the fuel in a research engine under various compression ratios and controlled settings [11]. Several studies have found that the higher the compression pressure in the combustion chamber, the higher the octane rating required to achieve optimal engine performance [12], [13], [14]. A study conducted by Zhang and his colleagues reported that increasing the compression ratio in an engine can effectively reduce fuel consumption [15]. An increase in the compression ratio raises the in-cylinder combustion temperature, alters dominant combustion mechanisms, and ultimately reduces hydrocarbon (HC) emissions [16].

Two categories of hydrocarbon compounds resulting from the petroleum refining process were selected as the test fuels. Several refineries in Indonesia have produced gasoline distributed at fuel stations in the form of RON 88 and RON 92 gasoline. These products were chosen for testing purposes because they represent the types of gasoline commonly available in the Indonesian market [17]. Unfortunately, many consumers are not aware that engines with high compression ratios require high-octane fuel to achieve optimal performance. This can be seen from recent statistical data published by the Directorate General of Oil and Gas, which shows that the sales volume of RON 90 gasoline is far higher than that of RON 92 or RON 95 gasoline [18]. This data clearly shown that many consumers still choose lower-octane gasoline for use in modern vehicle engines, which generally have high compression ratios. Based on the explanation above, we will conduct performance testing using a dynamometer on a single-cylinder engine with compression ratios of 9.6:1 and 10.6:1. Each test will use Premium (RON 88) and Pertamax (RON 92) fuels to observe differences in brake power and torque output.

2 Methodology

In this study, an experimental method was used involving a 124cc single-cylinder motorcycle engine. This engine was selected because most vehicles in Indonesia use a single-cylinder engine with a 124cc capacity. Table 1 presented the engine specifications.

Table 1. Engine specifications for performance testing

Engine type	**4-stroke, SOHC**
Cylinder capacity (cc)	124
Bore x stroke (mm x mm)	53,5 x 55,2
Compression ratio	9,6: 1
Fuel supply	Carburetor
Ignition system	CDI

The engine compression ratio was adjusted by reducing the cylinder thickness to alter the effective cylinder volume. The initial combustion chamber volume was calculated as presented in Equation (1). The compression ratio (CR) is defined as the ratio between the maximum cylinder volume at bottom dead center (BDC) and the minimum cylinder volume at top dead center (TDC). The volume at TDC corresponds to the clearance volume (Vc), while the volume at BDC is the sum of the swept volume (Vs) and the clearance volume (Vc). Accordingly, the compression ratio is mathematically expressed as follows:

$$\boldsymbol{CR = \frac{V_{BDC}}{V_{TDC}} = \frac{Vs + Vc}{Vc}} \quad (1)$$

Figure 1, which illustrates the initial position of the piston at Top Dead Center (TDC) before the cylinder thickness reduction. Reduction of 0.6 mm in cylinder thickness was carried out to increase the compression pressure of the engine. Due to this modification, it was necessary to calculate the cylinder volume after the reduction using Equation (2), where 'S' represents the cylinder thickness value after reduction, and 'D' represents the cylinder diameter.

$$\boldsymbol{Vcylinder2 = \frac{3.14\ x\ D^2\ x\ S}{4}} \quad (2)$$

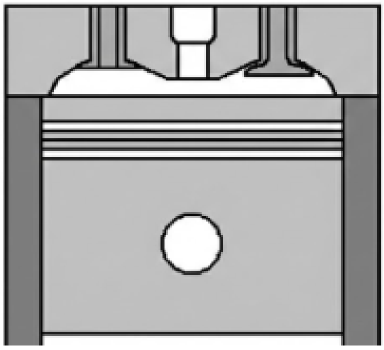

Fig. 1. Initial piston position at top dead center

A cylinder thickness reduction of 0.6 mm was applied, which also affect the piston stroke volume (V_s). The cylinder volume must be recalculated using Equation (2). In addition, the result of this second reduction also changed the engine's compression ratio to 10.6:1, compared to the initial standard compression ratio of 9.6:1. The piston position inside the cylinder after the 0.6 mm cylinder thickness reduction can be seen in Figure 2.

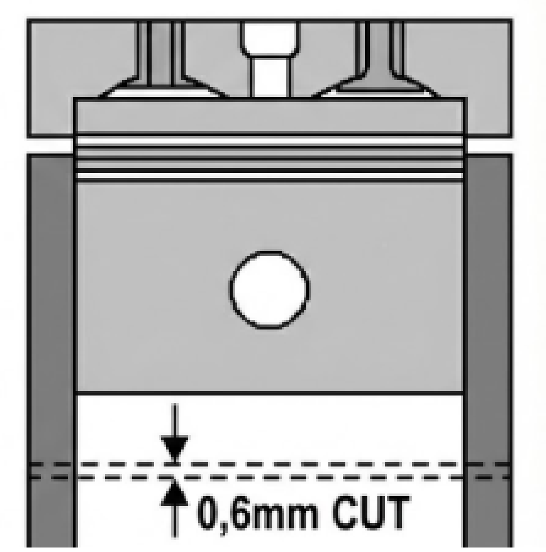

Fig. 2. Piston position at top dead center (TDC) after cylinder thickness reduction of 0,6 mm

The main jet and pilot jet settings, as well as the number of idle screws turns on the carburetor, were kept constant throughout the testing. The engine performance parameters can be calculated using Equation (3), where (T) represents the work (or torque-related work) done by a force (F) acting along a displacement (δr) at a position vector (r). It describes the accumulated contribution of the force over the path of motion.

$$\boldsymbol{T = \int r \, . \, F \, \delta r} \tag{3}$$

The power produced can be calculated using Equation (4), where 'N' represents the rotational speed of the crankshaft (RPM) and the notation 'BP' represents the brake power value.

$$\boldsymbol{BP = \frac{2\,\pi\,N\,T}{60\,x\,1000}} \tag{4}$$

The fuels used in this study were those produced by Pertamina, namely Premium (RON 88) and Pertamax (RON 92). These fuels were selected based on their availability compared to those from other private refineries, as well as the fact that the majority of Indonesia's population still uses these two types of fuel. The properties of RON 88 and RON 92 gasoline are presented in Table 2.

Tabel 2. Fuel specifications for testing

Items	**Premium**	**Pertamax**
RON	88	92
Caloric value (kj/kg)	43031	43848
distilation;		
10% evap. Volume (°C)	74	70
50% evap. Volume (°C)	125	110
Boiling point (°C)	215	215
Density at 15°C	780	770

The test data results were converted into tables and graphs to facilitate interpretation. The equipment used in the performance testing included a dynamometer and additional tools such as a set of hand tools, a measuring burette and a stopwatch. Before conducting the dynamometer test, the motorcycle must be positioned correctly, with the rear wheel aligned precisely above the dynamometer roller.

The tachometer cable must be connected to the high-voltage cable leading to the spark plug. Next, the hose connected to the carburettor must be removed and replaced with a hose from the measuring burette. The burette will be filled alternately with RON 88 and RON 92 fuel. The dynamometer test setup is shown in Figure 3. Once all preparations are complete, the performance test can be carried out by two people, with one person operating the motorcycle while the other handles the computer/testing software.

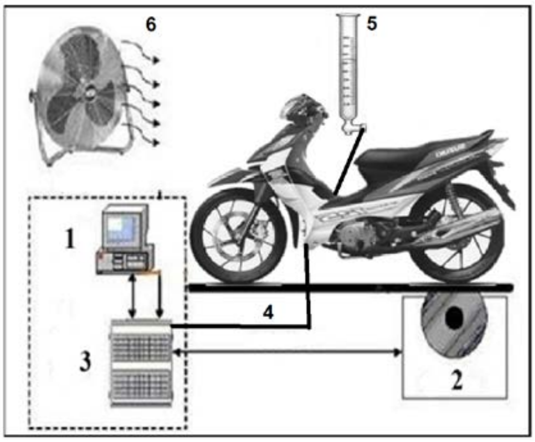

Fig. 3. Dynamometer testing scheme: (1) monitor, (2) dynamometer roller, (3) GPU (graphic processing unit), (4) high-tension cable, (5) measuring burret, (6) blower fan

3 Result and discussion

Torque output testing was conducted on a 124cc motorcycle engine using RON 88 and RON 92 fuels and two types of compression ratios (CR 9.6:1 and CR 10.6:1). Figure 4 shows the torque test results for the two different compression ratios using RON 88 gasoline. In general, the engine with the higher compression ratio (10.6:1) produced greater torque compared to the engine with the lower compression ratio (9.6:1), although the difference was not particularly significant [14], [19]. For example, at 4000 rpm, the engine with the higher compression ratio was able to produce 0.16 Nm more torque compared to the engine with the lower compression ratio at the same engine speed.

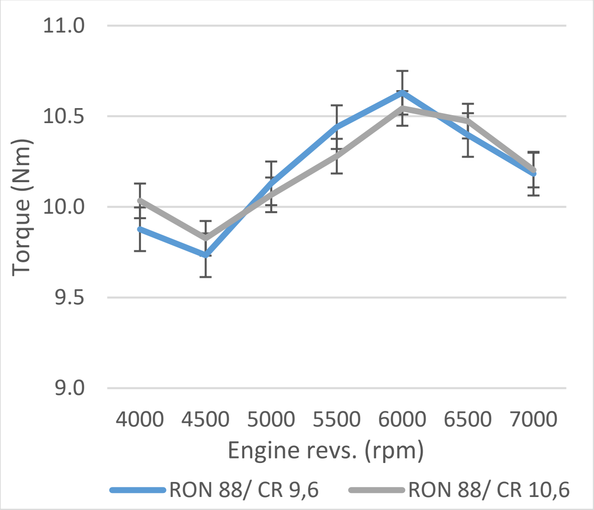

Fig. 4. Torque output results of engines with CR 9.6:1 and 10.6:1 using RON 88 gasoline.

In the next comparison, engines with the same compression ratio (9.6:1) were tested using two types of gasoline (RON 88 and RON 92). Figure 5 shows that the torque output produced by the engine with a 9.6:1 compression ratio using RON 92 gasoline tended to be lower compared to the same engine using RON 88. This confirms findings from previous studies, which state that using high-octane gasoline in a low-compression engine results in less optimal combustion due to the occurrence of ignition delay [20], [21]. Overall, the engine with a low compression ratio (9.6:1) fueled with RON 92 produced approximately 2.4% less torque than the same engine fueled with RON 88. Differences in the caloric value of the two gasoline fuels also influence the resulting brake power output. Fuels with higher octane number generally possess higher caloric values, which contribute to increased torque generation when utilized in the engine [22], [23].

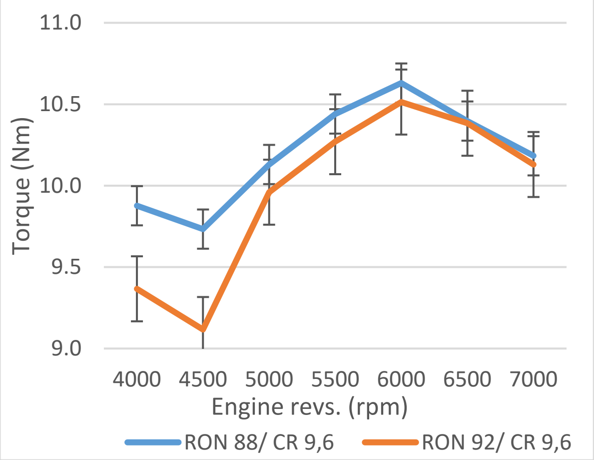

Fig. 5. Torque output results of engines with CR 9.6:1 using RON 88 & RON 92 gasoline.

The next comparison involves examining the torque output of engines with two different compression ratios (9.1:1 and 10.6:1) using RON 92 gasoline. Figure 6 provides a clear illustration of the torque output produced by the engines across the 4000 to 7000 rpm range. In general, the engine with a 10.6:1 compression ratio was able to produce better torque output across all engine speeds. The combination of high-octane gasoline and a high compression ratio results in optimal torque output [13], [24]. Overall, the average torque produced by the high-compression engine was approximately 4% greater than that of the low-compression engine.

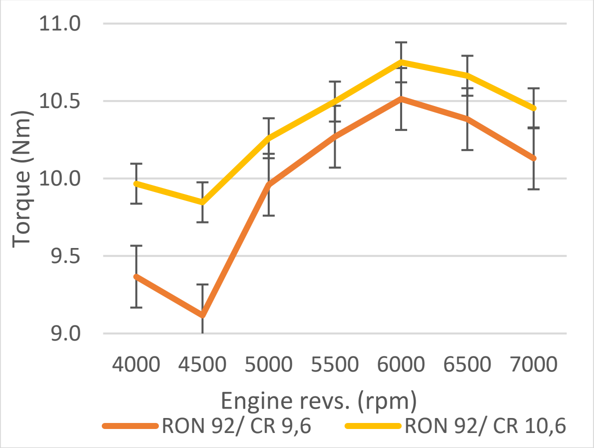

Fig. 6. Torque output results of engines with CR 9.6:1 & 10,6 :1 using RON 92 gasoline.

A comparison was also conducted between two gasoline octane ratings (RON 88 and RON 92) used in the high compression ratio engine (10.6:1). Figure 7 shows the difference in torque produced by the high-compression engine when using the two types of gasoline. The engine with a high compression ratio produced greater torque when fueled with RON 92. Only at low engine speed (4000 rpm) did RON 88 record slightly higher torque, but at higher engine speeds (5000–7000 rpm), RON 92 was able to deliver more optimal torque in the high-compression engine. This is because, at high engine speeds, a faster combustion cycle is required, and the fuel's ability to resist self-ignition under high pressure becomes crucial to achieve an optimal combustion cycle. This is related to the phenomenon of detonation or pre-ignition, which causes the air–fuel mixture to ignite at the wrong time, resulting in suboptimal torque output [25], [26].

Torque is one of the indicators of optimal combustion of the air–fuel mixture. When the engine's compression ratio and the fuel's octane number are appropriately matched, optimal torque output can be achieved. Figure 8 shows the torque output test results for two compression ratio variations (9.6:1 and 10.6:1) using two gasoline octane ratings (RON 88 and RON 92). At a glance, it appears that the high-compression engine (10.6:1) using high-octane fuel (RON 92) produces the best torque output compared to the others. On the other hand, the low-compression engine (9.6:1) supplied with high-octane fuel (RON 92) actually produces lower torque output. This phenomenon further confirms that high-octane gasoline, which has a greater resistance to self-ignition, is less optimal when forced to be used in a low-compression engine [3], [12].

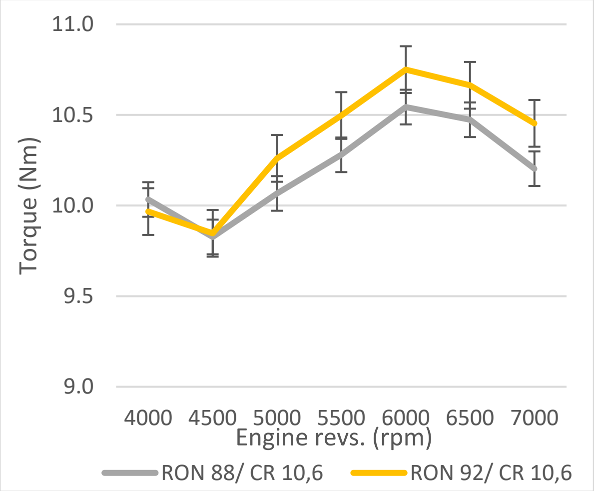

Fig. 7. Torque output results of engines with CR 10.6:1 using RON 88 & RON 92 gasoline.

Another notable observation is seen in engines with compression ratios of 9.6:1 and 10.6:1 when using RON 88 gasoline. In these two scenarios, the torque output of both engines shows no significant difference, and at a glance, they even appear to exhibit similar patterns. This indicates that a low-compression engine (9.6:1) is better suited for lower-octane gasoline (RON 88). However, a high-compression engine (10.6:1) supplied with low-octane gasoline does not produce optimal torque. This also reinforces previous findings [23], [24], [27], stating that high-compression engines require high-octane gasoline to achieve optimal torque output.

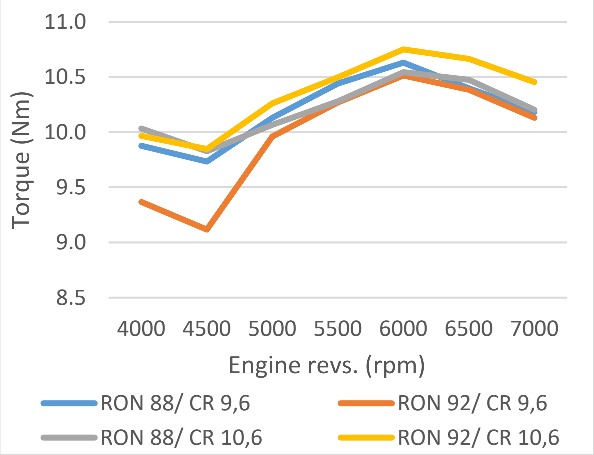

Fig. 8. Torque output results of engines with CR 9,6 :1 & 10.6:1 using RON 88 & RON 92 gasoline.

Power output testing was carried out on a 124cc motorcycle engine using RON 88 and RON 92 fuels and two types of compression ratios (CR 9.6:1 and CR 10.6:1). Figure 9 presents the brake power output test results for the two different compression ratios using RON 88 gasoline. In general, the engine with the higher compression ratio (10.6:1) produced slightly better brake power compared to the engine with the lower compression ratio (9.6:1) [19]. This is because a more ideal combustion cycle occurs in a high-compression engine, which is able to compress the air–fuel mixture more densely, resulting in more optimal brake power generation [25], [28]. On average, the engine with a 10.6:1 compression ratio was able to produce 3.9% more brake power compared to the engine with the lower compression ratio (9.6:1).

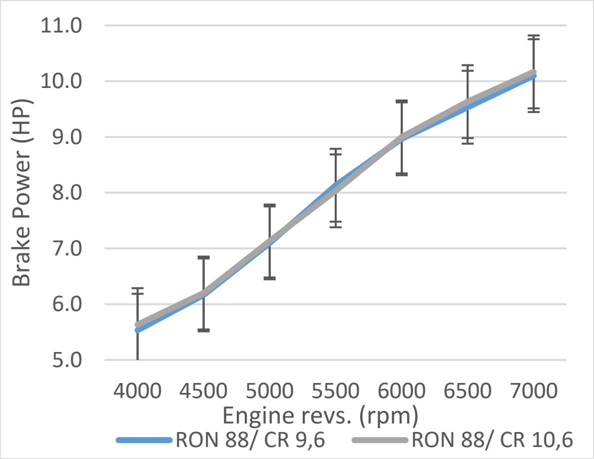

Fig. 9. Brake power output results of engines with CR 9.6:1 and 10.6:1 using RON 88 gasoline.

In the next scenario, a comparison was made between engines with the same compression ratio (9.6:1) but using two different types of fuel, namely RON 88 and RON 92. Based on Figure 10, it can be seen that the brake power output of the 9.6:1 compression ratio engine using RON 92 gasoline tends to be lower than that of the engine using RON 88. This finding is consistent with previous studies, which state that using higher-octane fuel in a low-compression engine can lead to less optimal combustion due to ignition delay [20], [21]. Overall, the brake power produced by the 9.6:1 compression ratio engine using RON 92 was approximately 2.1% lower compared to the same engine using RON 88.

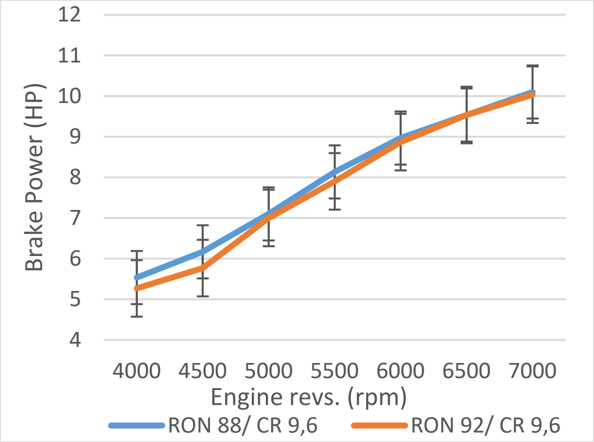

Fig. 10. Brake power output results of engines with CR 9.6:1 using RON 88 & RON 92 gasoline.

The next comparison was carried out by evaluating the brake power output of engines with two different compression ratios, namely 9.6:1 and 10.6:1, both using

RON 92 gasoline. As shown in Figure 11, the engine with a 10.6:1 compression ratio clearly produces higher brake power across the entire speed range of 4000 to 7000 rpm. This indicates that increasing the compression ratio in an engine operating with high-octane fuel can enhance combustion performance, leading to a more complete combustion process and higher brake power output [14], [24]. Overall, the engine with the higher compression ratio generates an average brake power that is approximately 3.68% greater than that of the engine with a 9.6:1 compression ratio.

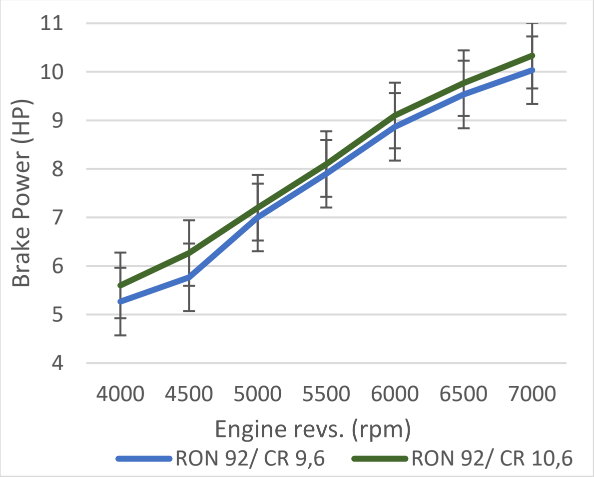

Fig. 11. Brake power output results of engines with CR 9.6:1 & 10,6 :1 using RON 92 gasoline.

A further analysis was conducted to compare the use of two types of gasoline with different octane ratings (RON 88 and RON 92) in the high-compression engine (10.6:1). As illustrated in Figure 12, the engine generally produces higher brake power when using RON 92 gasoline. At lower speeds (around 4000 rpm), RON 88 produces slightly higher brake power. However, at higher engine speeds (5000–7000 rpm), RON 92 delivers a more optimal brake power output. These findings indicate that high-octane fuel is more suitable for high-compression engines because it offers better resistance to knocking, allowing the combustion process to occur more stably at medium to high engine speeds. This occurs because, at high engine speeds, the combustion process must take place rapidly and remain stable. The fuel's ability to resist the tendency for self-ignition under high pressure becomes crucial to ensure that the combustion cycle operates optimally. Otherwise, detonation or pre-ignition may occur, in which the air–fuel mixture ignites before the intended ignition timing. This condition reduces combustion efficiency and decreases engine brake power output [25], [26].

Brake power output also serves as a key indicator of the effective combustion of the air–fuel mixture. When the engine operates with an appropriate compression ratio and a matching fuel octane rating, optimal brake power generation can be achieved. Figure 13 presents the measured brake power output for two compression ratios (9.6:1 and 10.6:1) combined with two gasoline octane ratings (RON 88 and RON 92). Fuels with higher octane ratings typically exhibit greater caloric values, thereby contributing to higher engine brake power output [22], [23].

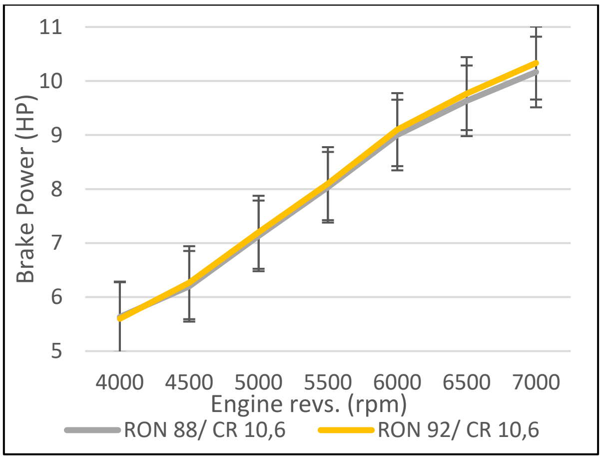

Fig. 12. Brake power output results of engines with CR 10.6:1 using RON 88 & RON 92 gasoline.

At a glance, it is evident that the high-compression engine (10.6:1) fueled with high-octane gasoline (RON 92) produces the highest brake power output compared with the other combinations. Conversely, the low-compression engine (9.6:1) supplied with RON 92 generates noticeably lower brake power. This finding further supports the premise that high-octane fuels designed to resist self-ignition are less effective when used in engines with low compression ratios [3], [10].

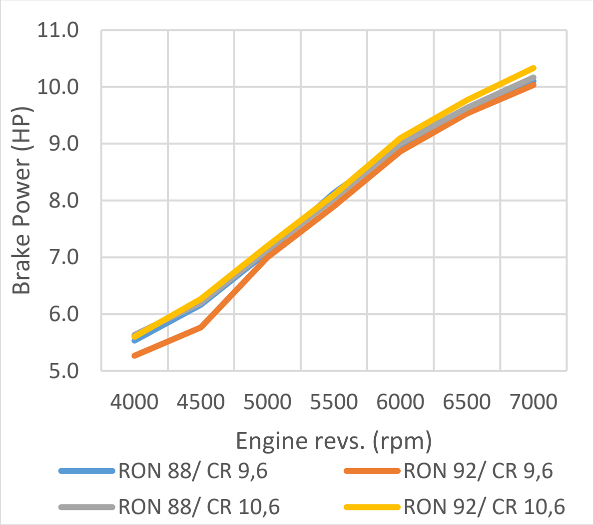

Fig. 13. Brake power output results of engines with CR 9,6 :1 & 10.6:1 using RON 88 & RON 92 gasoline.

A similar phenomenon is also observed when both compression ratios (9.6:1 and 10.6:1) are operated using RON 88. In this configuration, the brake power outputs of the two engines show minimal differences and exhibit nearly identical trends. This indicates that low-octane gasoline (RON 88) is more suitable for engines with lower compression ratios (9.6:1), whereas its use in high-compression engines (10.6:1) results in suboptimal brake power generation. These results are consistent with previous studies [10], [18], [21], which highlight that high-compression engines require high-octane fuels to achieve optimal brake power output.

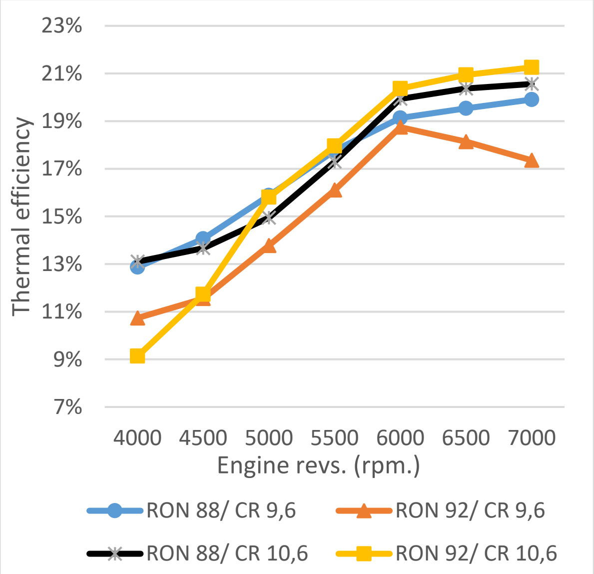

Fig. 14. Thermal efficiency of engines with CR 9,6 :1 & 10.6:1 using RON 88 & RON 92 gasoline.

The graph at Figure 14 shows a consistent increase in thermal efficiency as engine speed rises from 4000 to 7000 rpm for all gasoline octane and compression ratio combinations. This trend indicates that, within this operating range, higher engine speed promotes more effective air–fuel mixing, faster combustion, and relatively lower heat losses compared to the useful work produced. However, beyond approximately 6000 rpm, the rate of efficiency improvement begins to level off, suggesting that the engine is approaching its optimal combustion condition [29], [30]. A clear difference is observed between the two compression ratios. Engines operating at a compression ratio of 10.6 consistently exhibit higher thermal efficiency than those at 9.6 across all engine speeds. This observation aligns with the Otto cycle principle, where higher compression ratios lead to increased in-cylinder pressure and temperature during combustion, allowing a greater portion of the fuel's chemical energy to be converted into mechanical work [31], [32].

The effect of fuel octane number becomes more evident when examined in relation to compression ratio. At the higher compression ratio (CR 10.6), the use of RON 92 fuel results in slightly better thermal efficiency compared to RON 88, indicating that higher octane fuel effectively prevents knocking and enables combustion to occur at optimal timing. In contrast, at the lower compression ratio (CR 9.6), the use of RON 92 does not provide a noticeable advantage and even shows slightly lower efficiency at higher engine speeds. This suggests that the slower combustion characteristics of higher octane fuel are not fully utilized under lower compression conditions [20], [33].

These findings demonstrate that thermal efficiency is not solely determined by the octane number of the fuel but is strongly influenced by the compatibility between fuel characteristics and engine compression ratio. Increasing the compression ratio has a more significant impact on improving thermal efficiency than increasing the fuel octane number, and higher octane fuel provides optimal benefits only when matched with a higher compression ratio [14], [22].

4 Conclusion

Based on the performance tests of a 124cc engine with varying compression ratios (9.6:1 and 10.6:1) and fuel types (RON 88 and RON 92), it can be concluded that the combination of a high compression ratio and high-octane fuel yields the most optimal torque and brake power output. Meanwhile, low-compression engines tend to perform better when operated with low-octane gasoline. Overall, selecting a fuel with an appropriate octane rating for a given compression ratio is essential to achieving optimal torque and brake power output.

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