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Influences of Compression Ratio on Performance of Single Cylinder Otto Engine Using E50 Fuel

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***Abstract*—Ethanol mixed with a primary fuel is a promising alternative fuel. To increase performance, an optimal compression ratio must be set. The compression ratio is the ratio of the maximum volume divided by the minimum volume. Ethanol-gasoline mixtures have high octane and can be used in high-compression engines. This research aims to identify how changes in compression ratio can affect various aspects of engine performance, including torque, power, fuel efficiency, and thermal efficiency. This study is expected to reveal new insights that can aid in optimizing engine performance and developing a more comprehensive understanding of the characteristics of the E50 fuel within the context of Otto engine usage. A single-cylinder Otto engine was used for testing. Compression ratios of 9.3:1, 10.3:1, and 11.3:1 were tested. The results showed that the compression ratio of 9.3:1 produces a peak torque of 7.17 N·m, peak power of 3.36 kW, lowest BSFC of 0.275 kg/kWh, and highest BTE of 37.49%. A compression ratio of 10.3:1 produces a peak torque of 7.21 N·m, peak power of 3.57 N·m, lowest BSFC of 0.281 kg/kWh, and highest BTE of 39.46%. A compression ratio of 11.3:1 produces a peak torque of 7.73 N·m, peak power of 3.81 kW, lowest BSFC of 0.275 kg/kWh, and highest BTE of 40.36%. Compared with pertalite, E50 reduces torque by 9.25%, power by 9.93%, BSFC by 3.66%, and BTE by 8.76% at all compression ratios.**

***Keywords*—ethanol, compression ratio, engine performance, E50 and pertalite**

I. INTRODUCTION

The increase in the number of motorized vehicles, particularly two-wheeled vehicles, can be attributed to several key factors, including their practicality and popularity in addressing people's mobility needs within the context of current road conditions. Two-wheeled vehicles have emerged as an exceptionally viable solution because of their inherent maneuverability and adaptability, which enable them to navigate congested roads and limited spaces with relative ease [1]. As urban areas become more densely populated and traffic congestion becomes a pervasive challenge, the compact nature of two-wheeled vehicles makes them attractive choices for efficient transportation [2].

Parallel to the surge in two-wheeled vehicles, a considerable improvement has been achieved in engine performance. Manufacturers have responded to the growing demand for improved performance by enhancing the power, efficiency, and technological features of these vehicles. This progress in engine capabilities has contributed to a more satisfying driving experience and has also made two-wheeled vehicles a more compelling option for individuals seeking convenience and enhanced performance [3]. Further enhancement in performance can be achieved by improving the fuel efficiency of internal combustion engines. All machines require fuel to perform the cycle work. Currently, gasoline is the most commonly used fuel. Gasoline has a high octane number but low engine efficiency [4]. As the number of motorized vehicles continues to grow, the corresponding increase in the utilization of fuel oil contributes to the depletion of petroleum-based energy sources.

The community's dependence on fuel oil remains high. In 2019, fuel consumption increased by 3%, with a fuel consumption of 75 KL [4]. In addition, the fuel used in today's engines produces emissions that are detrimental to human health and the ecosystem. One solution for reducing fuel oil depletion is to generate renewable energy [5, 6]. According to Koc *et al.* [7], reducing the increasing use of fuel oil requires continued efforts to develop technologies for alternative fuels that can be used without changing the structure of the engines of existing vehicles.

Ethanol, or ethyl alcohol, is a promising candidate for an alternative fuel that can be used by mixing with a primary fuel [8]. It can undergo complete combustion and reduce exhaust emissions. Ethanol is most compatible for mixtures with gasoline and can be used in internal combustion engines [9]. Ethanol blended with unleaded gasoline can be used as an alternative fuel without changing the engine structure [10].

To achieve better efficiency and enhance performance factors such as torque, power, specific fuel consumption,

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and brake thermal efficiency, appropriate compression setting adjustments must be made for fuel blends containing ethanol. Ethanol mixtures possess high octane values, making them suitable for high-compression engines [11].

Expanding on this idea, scientists plan to focus on novel viewpoints by conducting research and experiments to investigate how changes in the compression ratio affect the operational efficiency of single-cylinder Otto engines operating on E50 fuel. By incorporating this inventive methodology, this study is expected to generate a deeper understanding and innovative solutions that could drive further progress in this domain.

II. LITERATURE REVIEW

Hasan [10] compared the effect of different compression ratios when 70% ethanol, or E-70, was used as the fuel. The compression ratios used were 11:1 (standard) and 12.5:1. The results of this study showed that the torque at 12.5:1 compression was 14.239 N·m, which is a 2.9% increase over the torque generated by a standard engine. The generated power was 11.659 kW, an increase of 2.1% over that generated by the standard engine. Moreover, the resulting consumption was slightly increased at specific rotations because the load received by the engine at low rpm was greater than at high rpm [12].

Lesmawanto *et al.* [13] performed a compression comparison on a 4-stroke engine using 100% ethanol, or E-100, as its fuel, with a focus on increasing fuel efficiency. The results show that the greater the compression, the lower the fuel consumption. At an engine speed of 1500 rpm and a compression ratio of 11:1, the engine consumed fuel at a rate of 11.83 mL/min. For a compression ratio of 13:1, the fuel consumption rate of the engine was 11.67 ml/min, whereas at a compression ratio of 15:1, it was 8.97 ml/min, an average decrease of 12.2%.

Lestari *et al.* [14] tested the effects of bioethanol on motor vehicle exhaust emissions. The fuels used were BE 0 (bioethanol 0%), BE 5 (bioethanol 5%), and BE 10 (bioethanol 10%), and the exhaust emissions measured were CO, CO_2, NO_X, and HC. The results showed that when BE 5 and BE 10 were used, the emission levels decreased by 8% and 27%, respectively.

Wibowo *et al.* [15] investigated the performance of a Spark-Ignition (SI) engine using RON 92 gasoline mixed with ethanol. The mixtures of gasoline and ethanol used were 40% (E40), 50% (E50), and 60% (E60). The E60 engine obtained a maximum torque and power of 12 N·m and 10 kW, respectively. The engine using E50 showed a brake fuel consumption of 320 g/kWh.

Calam *et al.* [16] focused on a Homogenous Charge-Compression Ignition (HCCI) engine, which is known for its superior thermal efficiency and minimal NOx and soot emissions. This study explored the impacts of various alternative fuels with distinct physical and chemical properties on the combustion, performance, and emissions of an HCCI engine. Alternative fuels, including ethanol (E25), methanol (M25), fusel oil (F25), butanol (B25), isopropanol (IP25), and naphtha (N25), were blended with n-heptane at a volume ratio of 25%. Experiments were conducted using a single-cylinder SI-HCCI test engine at an intake air temperature of 333 K with varying excess air coefficients.

Agrariksa *et al.* [17] conducted a performance test using a premium ethanol mixture. The engine used was a 4-stroke Otto engine with a capacity of 110 cc, and mixtures of 0%, 5%, 15%, and 25% ethanol-gasoline were used as the fuel. A compression of 9.3:1 (standard) using the 15% ethanol-gasoline mixture yielded the highest power (7.23 kW). Moreover, the 0% mixture produced the highest brake fuel consumption (0.25 kg/kWh).

Sudarmanta *et al.* [18] studied the effects of the compression ratio and ignition timing on a 650 cc two-cylinder Sinjai engine. The compression ratios used in this study were 9.6:1, 10.6:1, and 11.6:1. The fuel used was E50, or 50% gasoline-ethanol mixture. The results showed that a compression ratio of 11.6:1 yielded the maximum torque (49.58 N·m). The maximum power (17.88 kW) was obtained from the engine at a compression ratio of 11.6:1. The minimum E50 brake fuel consumption (0.30 kg/hp.h) was produced at a compression ratio of 11.6:1.

Majanasastra [19] studied the performance of a 113.7-cc single-cylinder gasoline engine fueled by E85 at compression ratios of 9.25:1, 9.50:1, 9.75:1, and 10.25:1. The maximum power (6.3 HP) was produced when premium fuel was used. Engines with premium fuel had the lowest brake fuel consumption, with an average of 0.16 kg/hp.h.

III. MATERIALS AND METHODS

In this study, an engine with a carburetor system and capacity of 100 cm^3 was used with a mixture of ethanol (E50) and pertalite as the fuel. The engine specifications are listed in Table I.

TABLE I. ENGINE SPECIFICATIONS

Engine Type	Cylinder	Bore × Stroke	Compression	Transmission	Type of Ignition
4 Langkah, SOHC 2 *Valve*	*Single*	50×49.5 mm	9:1	4-*speed* (N-1-2-3-4)	CDI-AC

The fuel used was a mixture of 50% gasoline and 50% ethanol (E50). The gasoline used was pertalite, and the ethanol used had a content of 96%. The performance of the gasoline-ethanol mixture was adjusted by compression.

Cylindrical gaskets with different thicknesses were installed in the cylindrical block. The compression ratio was varied by using gaskets of appropriate thicknesses. Gasket thicknesses of 1.3, 0.8, and 0.15 mm produce compression ratios of 9.3:1, 10.3:1, and 11.3:1, respectively, as shown in Fig. 1.

The test scheme is shown in Fig. 2. First, the fuel was mixed and tested using a bomb calorimeter. Second, the engine to be tested was adjusted. Finally, a Dynojet 250i dynamometer was used during the testing phase to determine the torque, power, and fuel consumption.

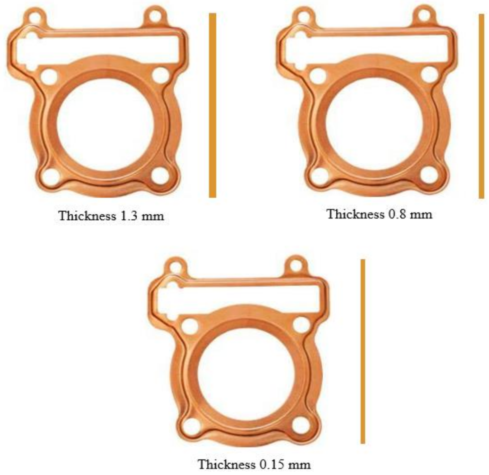

Fig. 1. Gasket cylinder.

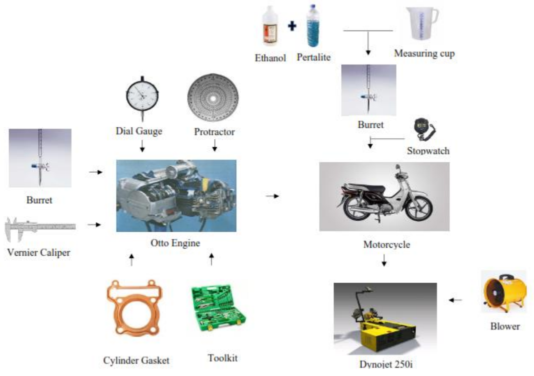

Fig. 2. Test scheme.

The Dynojet 250i uses eddy currents for load control. The torque and power data were obtained by placing the wheel output of the vehicle on the Dynojet 250i roller. The roller was connected to a disk that rotated in a controlled magnetic field. The eddy current brake system causes a braking effect on the disk. The drying effect was used to control the load and measure the engine torque. The outputs of the Dynojet 250i were power (bhp) and torque (ft. lbs).

Brake-Specific Fuel Consumption (BSFC) and Brake Thermal Efficiency (BTE) were calculated as follows:

Brake-Specific Fuel Consumption (BSFC):

$$\dot{m}_f = \left(\frac{V}{t}\right)\rho \tag{1}$$

$$bsfc = \frac{\dot{m}_f}{Bp} \tag{2}$$

Brake thermal efficiency:

$$\eta_{tb} = \frac{Bp}{\dot{m}_f Q_{lhv}\ \eta_e} \tag{3}$$

IV. RESULT AND DISCUSSION

During the test, the engine was used in third gear at full throttle, with the engine speed ranging between 3,000 and 9,000 rpm. The remaining fuel flow rate data were obtained by removing the fuel tank hose and replacing it with a measurement tube (buffet). The time taken by the engine to consume every 10 mL of fuel was measured using a stopwatch at engine speeds ranging from 4,000 to 8,000 rpm in multiples of 1,000 rpm. In addition, the experiment was repeated using only gasoline and then only E50 as the fuel. All the fuels were tested using the variable-speed engine method.

The differences in the calorific value and density of the E50 and pertalite fuels are listed in Table II. The calorific value and density of the fuel are required to calculate the brake thermal efficiency and brake-specific fuel consumption, respectively, of the engine. The greater the ethanol content in the fuel mixture, the lower the calorific value of the fuel.

TABLE II. FUEL SPECIFICATIONS [20]

Num	Properties	Unit	Value of Fuel Properties	
			E50	Pertalite
1.	Density	Gr/mL	0.76565	0.74250
2.	Lower Heating Value	Cal/g	7916.40	11089.8

A. Torque and Power

Torque is the force required to rotate an object about an axis. Power is defined as the rate of doing work [21, 22]. The combustion in the engine at a high compression ratio was more complete than at a low compression ratio. With complete combustion, torque and power increase [23]. The torque and power at a compression ratio of 11.3:1 were higher than those at compression ratios of 10.3:1 and 9.3:1.

Based on the test results in Fig. 3 and 4, torque and power increased with the compression ratio. The highest torque value was 7.40 N·m, which was produced when the fuel was ethanol, compression ratio was 11.3:1, and engine speed was 3,000 rpm. The highest power value (3.80 kW) was obtained with ethanol as the fuel at a compression ratio of 11.3:1 and engine speed of 8,000 rpm. Increasing the compression ratio causes the combustion to be more complete, which, in turn, maximizes torque and power.

Pertalite was found to be superior to E50 in maximizing torque and power. This is because E50 had a smaller calorific value; thus, it produced less energy when combusted [24]. Because the E50 carburetor settings were not varied, the E50 mixture in the carburetor was rich in air, which is considered a poor mixture (lean) [25]. Because of poor mixing, engine performance was slower [26]. When pertalite was used, the best torque (7.72 N·m) was produced at a compression ratio of 11.3:1 and an engine speed of 3,000 rpm. Meanwhile, the highest power delivered by the pertalite fuel was 4.36 kW, which was produced at an engine speed of 8,000 rpm.

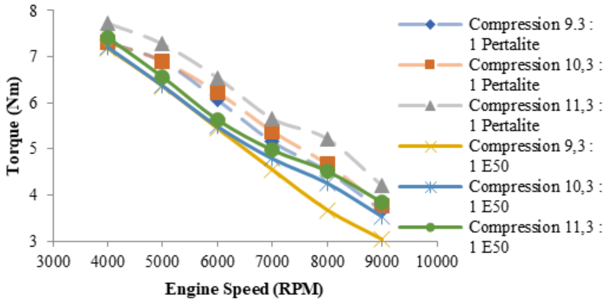

Fig. 3. Torque for all compression variations using E50 and gasoline.

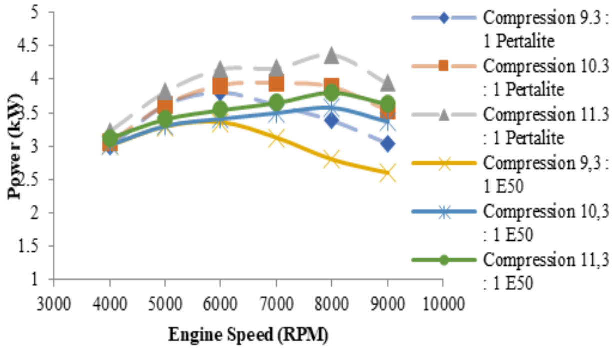

Fig. 4. Power for all compression variations using E50 and gasoline.

B. *Brake-Specific Fuel Consumption and Brake Thermal Efficiency*

Fig. 5 shows the BSFC values as a function of engine speed for different compression ratios and fuel types. The BSFC values measure the amount of fuel consumed by the engine to produce a power of 1 kW for 3600 s or 1 h [27]. The lowest BSFC value for ethanol fuel was 0.275 kg/kWh, produced at a compression ratio of 11.3:1 and an engine speed of 5,000 rpm. The lowest BSFC values for ethanol at an engine speed of 5,000 rpm and compression ratios of 10.3:1 and 9.3:1 were 0.281 kg/kWh and 0.296 kg/kWh, respectively. The BSFC values decreased to the lowest point and then increased as the engine speed increased. This is because during initial rotation, the engine requires a large amount of fuel to drive all components [28]. The BSFC value is related to the engine power, which changes at every engine speed. Therefore, the BSFC value calculated using Eq. (2) changes with engine speed.

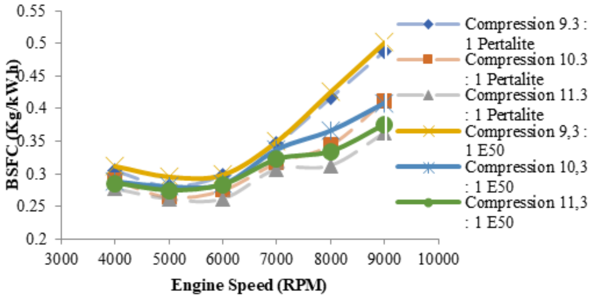

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Fig. 5. Brake-specific fuel consumption for all compression variations using E50 and gasoline.

Fig. 6 shows the BTE values as a function of engine speed for different compression ratios and fuel types. The BTE values are determined as a percentage. The highest BTE value (40.36%) for the ethanol fuel was produced at a compression ratio of 11.3:1 and an engine speed of 5000 rpm. The highest BTE value for a compression ratio of 10.3:1 and an engine speed of 5000 rpm was 39.46%, whereas for a compression ratio of 9.3:1 and the same engine speed, it was 37.49%. The BTE value depends on the fuel mixture in the combustion chamber. Increasing the compression ratio causes the fuel flow rate to decrease, which increases complete combustion [15]. Improved combustion maximizes torque and power.

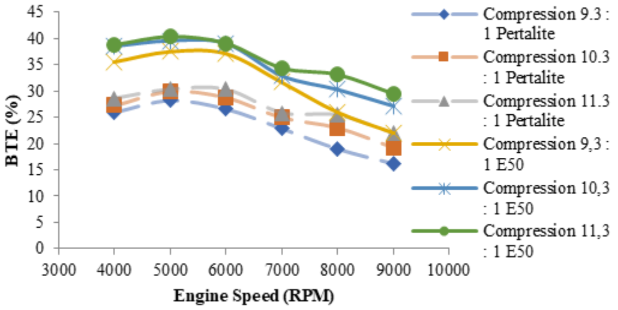

Fig. 6. Brake thermal efficiency for all compression variations using E50 and gasoline.

Pertalite had a lower BSFC value than ethanol-fueled BSFC. The lowest BSFC of pertalite fuel was 0.261 kg/kWh. This is because ethanol fuel has a higher density. At a higher density, fuel usage is wasteful, leading to a high BSFC value [29]. The BTE value for E50 increases proportionately with the air-fuel ratio and calorific value of E50 [30]. With a suboptimal ratio of air to fuel, the power generated is also suboptimal. Fuel with a low calorific value produces a smaller amount of energy, and thermal efficiency becomes important. Thus, the BTE value for E50 was superior to that for pertalite, which exhibited the highest BTE value of 30.35% at an engine speed of 5,000 rpm.

V. CONCLUSION

The results of the engine performance test showed that using E50 fuel with standard compression on a Honda Grand motorcycle with a cylinder capacity of 100 cc decreased the engine performance in terms of torque, power, and brake thermal efficiency. The decrease in engine's performance causes brake-specific fuel consumption to be greater than that of pertalite fuel. The E50 fuel with a compression of 11.3:1 produces high torque, power, and brake thermal efficiency of 7.40 N·m, 3.80 kW, and 40.35%, respectively. The E50 fuel can yield similar power and torque values as obtained with pertalite, with average power and torque values of 90.75% and 90.07%, respectively. In addition, BSFC and BTE increase by 3.66% and 8.76%, respectively. This is because of the nature of ethanol fuel, which has a lower heating value and higher density than pertalite.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, W.E.J., I.Y., A.Y.N., R.A.R., and Z.A.; methodology, A.Y.N., W.E.J., R.A.R, S.D.P. and Z.A.; validation, D.D.D.P.T., S.S., S.D.P., and Z.A.; formal analysis, AY.N., R.A.R., I.Y., S.D.P. and Z.A.; investigation, A.Y.N., W.E.J., R.A.R., and S.D.P.; resources, W.E.J., A.Y.N., S.D.P. and I.Y.; data curation, S.D.P., W.E.J., R.A.R., D.D.D.P.T., and S.S.; writing—original draft preparation, W.E.J., A.Y.N. S.D.P. and

R.A.R.; writing—review and editing, W.E.J., I.Y., D.D.D.P.T., S.S. and Z.A.; visualization, W.E.J., A.Y.N., S.D.P. and R.A.R.; supervision, W.E.J. and Z.A.; project administration, W.E.J., S.D.P., and Z.A.; funding acquisition, W.E.J. and Z.A. All authors have read and agreed to the published version of the manuscript.

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