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Durability analysis of four-stroke motorcycle engines using juken BRT ECU and iridium spark plugs with bioethanol fuel

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Abstract

The heavy reliance on fossil fuels in Indonesia has accelerated the search for renewable and eco-friendly alternatives, such as bioethanol. This study aims to analyze the effect of using a programmable ECU and iridium spark plug with a 30% bioethanol–70% Pertalite fuel blend on the durability of four-stroke motorcycle engines. An experimental method was applied with three treatments: standard (no modification), treatment 1 (350° injection timing, 5° ignition timing), and treatment 2 (350° injection timing, 9° ignition timing). Durability tests were conducted for 20, 40, and 50 hours. The results indicate that treatment 2 produced the lowest carbon deposit, 150 mg with a volume of 83 mm³, compared to the standard treatment (680 mg and 378 mm³). These findings highlight that optimizing ignition timing and using bioethanol fuel blends can reduce carbon deposits, improve combustion efficiency, and extend engine lifespan.

Keywords

Bioethanol, Durability, ECU, Iridium, Spark plug

Introduction

The growing dependence on fossil fuels has become a critical concern due to their finite, non-renewable nature and declining availability. This situation has prompted efforts to develop more sustainable energy sources, including bioethanol. As a gasoline additive, bioethanol can improve combustion efficiency. Ethanol-Pertalite blends have been shown to raise octane number and enhance engine performance; however, if vehicle calibration is not adjusted accordingly, adverse effects on engine components may arise. A programmable ECU offers a practical solution by enabling the retuning of fuel injection and ignition timing to achieve more efficient combustion [1]. Spark plug selection also influences combustion quality and engine life. Iridium spark plugs are generally considered superior to conventional types because they provide a more stable spark, improve combustion efficiency, and help limit carbon deposit accumulation in the

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combustion chamber. Excessive deposits can trigger knocking, elevate operating temperatures, and reduce engine durability [2].

Previous studies reported positive outcomes when combining retimed fuel injection and ignition, iridium spark plugs, and bioethanol blends. For example, modifying injection timing from 360° to 350° with 5° ignition advance and a 30% ethanol blend reduced carbon monoxide (CO) emissions, while a 9° ignition setting under similar conditions more effectively reduced hydrocarbon (HC) emissions [3]. Building on these findings, the present study investigates the combined effects of a programmable ECU, an iridium spark plug, and bioethanol on the durability of four-stroke motorcycle engines. In this study, durability is defined as the engine's resistance to damage arising from multiple influences. External factors include service interval, mileage, and usage patterns, whereas internal factors involve engine age, fuel quality, lubricant performance, and material properties [4]. A key indicator of durability is the formation of particulate matter or carbon deposits within the combustion chamber. Such deposits may appear as soot (a softer residue that is relatively easy to remove) or as varnish/coke (hard deposits that adhere strongly). Combustion chamber deposits are associated with a range of operational issues and performance degradation [5].

Within this context, the role of a programmable ECU becomes pivotal for optimizing combustion. Through remapping, the ECU can align injection and ignition events with engine requirements, covering daily operation as well as performance-oriented use. By coordinating sensors and actuators, optimal configurations are determined with respect to air–fuel ratio, ethanol content in gasoline, and ignition and injection phasing to prevent misfire and other instabilities [6][7][8]. Furthermore, fuel characteristics are also central to the analysis. In Indonesia, Pertalite (RON 90) is commonly used and is suitable for compression ratios of approximately 9:1 to 10:1 [9][10]. Ethanol (C_2H_5OH), produced from agricultural feedstocks such as corn, cassava, and sago, has a high-octane number. Blending ethanol with gasoline can increase octane rating and improve combustion quality [11][12]. An ethanol-Pertalite blend not only enhances combustion but also increases resistance to knock under appropriate calibration [13]. In parallel, the ignition system plays a vital role: the spark plug initiates combustion, and spark quality directly affects combustion efficiency. Among commercially available types, such as copper, platinum, and iridium, premium plugs are often promoted for their potential to improve performance and fuel economy [14].

Based on the foregoing, this study focuses on analyzing carbon-deposit formation on the piston crown and within the combustion chamber to identify the treatment that yields the most favorable durability outcome. The study also evaluates the feasibility of deploying a combined programmable ECU, iridium spark plug, and bioethanol-gasoline blend in daily use, with the broader aim of contributing to the development of environmentally friendly fuel technologies that preserve engine durability.

Method

This study employed an experimental method to investigate cause effect relationships by manipulating specific variables and observing the outcomes [15][16]. Three treatment variations were designed in order to compare the level of engine durability through the measurement of particulate matter in the form of carbon deposits accumulated in the combustion chamber of a motorcycle engine. The experiment was carried out at the Workshop of the Department of Automotive Engineering, Faculty of Engineering, Universitas Negeri Padang, using a Honda Beat Pop motorcycle as the test object [3]. The overall research flow is presented in Figure 1.

The research began with a preparation stage, which included comprehensive maintenance and cleaning of the combustion chamber to ensure that the test engine was free from any initial carbon deposits. A compression test was then performed to verify that there was no leakage, thereby confirming that the engine was in proper condition for experimentation. Several instruments were prepared for this study, including a programmable ECU, an iridium spark plug, a documentation camera, and fuels consisting of pertalite and ethanol mixed in accordance with the experimental design.

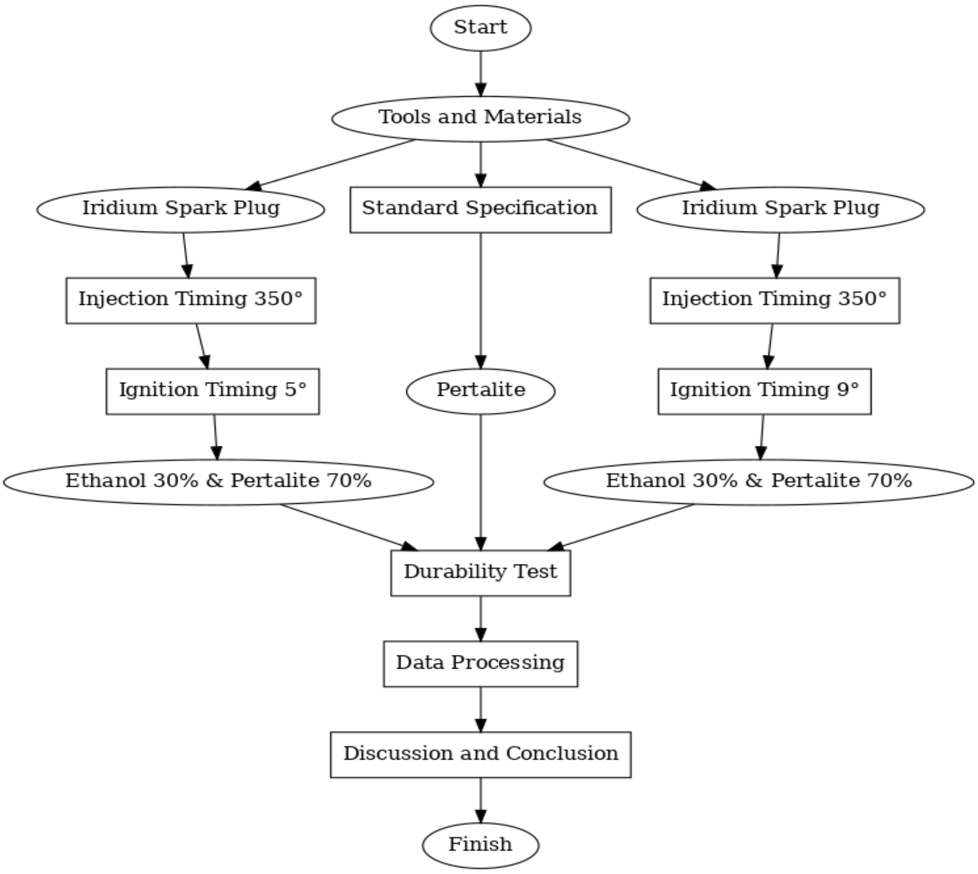

Figure 1. Research framework

The experimental phase consisted of three different treatments as shown in the flow chart. In the first treatment, the motorcycle was tested according to standard factory specifications without modification. The engine was operated for 20 hours (8 to 10 hours per day), after which it was disassembled to analyze carbon deposits in the combustion chamber and piston head. The same procedure was repeated after 40 hours and 50 hours of operation. At the end of the 50-hour cycle, carbon deposits were comprehensively measured in terms of mass (mg) and volume (mm^3), and visual documentation was performed using a camera.

In the second treatment, the motorcycle was modified by installing a programmable ECU with the injection timing set at 350° and the ignition timing at 5°. The standard spark plugs were replaced with iridium spark plugs, and the fuel used was a mixture of 70% pertalite and 30% ethanol. The operating procedure followed the same cycle as in the first treatment, with deposit measurements and documentation performed at the end of the 50-hour cycle. The third treatment followed the same procedure as the second treatment, with the only modification being an adjustment of the ignition timing to 9°. As in the previous phase, the engine was operated at intervals of 20, 40, and 50 hours, and at the end of the cycle, carbon deposits were measured and documented in detail. To ensure the reliability of the endurance test, the operating cycle did not stop at 50 hours but continued until a total of 110 hours was reached for each configuration. Thus, interim inspections at 20, 40, and 50 hours were used for visual documentation of deposit development, while the main quantitative measurements (carbon deposit mass and volume) were compared between treatments at the end of the total 110-hour test.

Upon completion of all experimental phases, the results were analyzed by comparing the three treatments standard specification, ECU programmable with injection 350° and ignition 5°, and ECU programmable with injection 350° and ignition 9°. The analysis focused on combustion characteristics, the extent of carbon deposit formation, and the influence of programmable ECU settings, iridium spark plugs, and pertalite–ethanol blends on the durability of a four-stroke engine. The volume of carbon deposits was calculated from the measured mass using the following equation:

$$V = \frac{m}{\rho} \qquad (1)$$

where V is the deposit volume (cm^3), m is the mass of the deposit (g), and ρ is the density of carbon. In this study, a conservative value of (ρ = 1.8 g\cm3) was assumed, consistent with reported ranges of soot and carbonaceous particle densities in combustion systems (typically 1.0–1.8 g/cm^3) as documented in previous studies [17][18].

Results and discussion

The endurance test was conducted for a total of 110 operating hours in three configurations: standard conditions (no modifications), Treatment 1 (iridium spark plugs, injection timing 350°, ignition timing 5°, 70% Pertalite–30% ethanol mixture), and Treatment 2 (iridium spark plugs, injection timing 350°, ignition timing 9°, same mixture). During testing, the engine was operated in 50-hour cycles with interim inspections at 20, 40, and 50 hours for visual documentation of carbon deposit development. After the first 50-hour cycle, the operating procedure was continued and repeated until a total of

110 hours was reached. A final quantitative measurement of the carbon deposit mass was performed at 110 hours using digital scales, and the volume was calculated from the mass assuming a conservative density of ρ = 1.8 g/cm³. Comparison of deposit mass and volume at 110 h shows in Table 1.

Table 1. Comparison of deposit mass and volume at 110 h

Condition	Duration (h)	Volume (mm³)	Mass (mg)
No treatment (standard)	110	378	680
Treatment 1	110	138	250
Treatment 2	110	83	150

Relative to the standard, Treatment 1 reduced deposit mass by ~63.2% (680 to 250 mg) and volume by ~63.5% (378 to 138 mm³). Treatment 2 delivered the largest effect, cutting mass by ~77.9% (680 to 150 mg) and volume by ~78.0% (378 to 83 mm³). The monotonic decline in both metrics across configurations is visualized in Figure 2, where the separation between the standard and treated conditions is pronounced and the steepest drop occurs in Treatment 2.

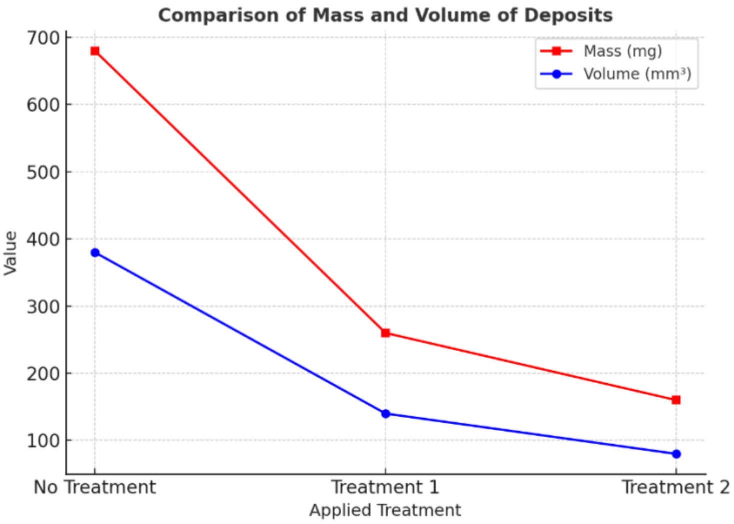

Figure 2. Mass and volume comparison chart of deposits

The results indicate that deploying an iridium spark plug, a programmable ECU calibration, and a 30% ethanol blend substantially suppresses combustion-chamber deposits, with the most effective configuration at 350° injection/9° ignition (Treatment 2). Because injection timing (350°) and the fuel blend were held constant across the two treatments, the additional improvement from Treatment 1 to Treatment 2 is most plausibly attributed to advancing ignition from 5° to 9°, which better aligns heat-release phasing with the oxygenated blend's knock resistance and promotes a more complete burn. The oxygen content of the E30 blend contributes to cleaner oxidation, while the iridium plug improves spark stability and early flame-kernel growth both of which tend to reduce the formation of soot precursors and the adhesion of deposits on the piston crown and chamber surfaces. From a durability standpoint, the >75% reductions in both mass and volume under Treatment 2 imply less insulating and abrasive material in the chamber, mitigating hot-spot formation and ring-land fouling and, over time, supporting more stable combustion. These inferences are consistent with the visual progression observed during intermediate inspections (20/40/50 h) and with the endpoint gravimetric measurements at 110 h.

As summarized in Table 1, Treatment 2 (iridium spark plug; injection timing 350°; ignition timing 9°; 70% Pertalite–30% ethanol) produced the lowest combustion-chamber deposits among all configurations. Relative to the standard condition, deposit mass fell from 680 mg to 150 mg (a 77.9% reduction) and volume decreased from 378 mm³ to 83 mm³ (a 78.0% reduction). Treatment 1 (same injection timing and blend, ignition 5°) provided intermediate benefits—63.2% (mass) and 63.5% (volume) reductions versus standard. These trends are consistent with Figure 3, which shows a monotonic decline in both metrics across the three configurations, with the steepest drop for Treatment 2. Mechanistically, advancing ignition from 5° to 9° while using an oxygenated E30 blend and an iridium plug plausibly improves combustion phasing and spark stability, thereby limiting soot-precursor formation and deposit adhesion.

Beyond the endpoint gravimetric results, Table 2 synthesizes visual inspections at 20, 40, and 50 hours. The standard condition exhibited earlier and thicker accumulation (already visible by 20 h and extensive by 50 h), whereas Treatment 1 showed thinner, more uniformly distributed layers. Treatment 2 maintained the cleanest surfaces across time, with only minor, non-obstructive deposits by 50 h. The qualitative progression in Table 2 corroborates the quantitative gap reported in Table 1. Operationally, there is a trade-off between combustion-chamber cleanliness and ride comfort. Table 3 consolidates rider-reported observations. The standard setup ran stably with light throttle response and no overheating. Treatment 1 introduced mild, intermittent hesitations near an empty fuel level and slightly harder cold starts, but hill-climb performance remained good. Treatment 2 despite its superior deposit control displayed early-phase drivability penalties (e.g., hesitation under heavy load >140 kg and limited high-rpm power on cold start), which diminished after ~50 hours, suggesting adaptation and/or improved mixture preparation with continued operation. These practical observations underscore the need for refined calibration (closed-loop fueling/ignition) to fully realize the durability benefits indicated by Tables 1–2 while minimizing the comfort penalties noted in Table 2.

Table 2. Visual progression of combustion-chamber deposits (20/40/50 h)

Timepoint	Duration (h)	Volume (mm³)	Mass (mg)
20 h	Thin deposits already visible; early yellowing of piston crown.	Thin, more uniform film; chamber close to baseline.	Cleanest appearance; only trace deposits.
40 h	Darkened chamber; thicker build-up, especially near dry-valve region.	Thin and evenly distributed layer; growth moderated.	Minimal accumulation; distribution remains uniform.
50 h	Heavy deposits covering much of piston/chamber surface.	Deposits present but controlled; do not impede surfaces.	Minor deposits within acceptable limits; surfaces largely clean.

Two caveats bound the interpretation. First, deposit volume is computed from mass using a conservative density assumption (ρ = 1.8 g\cm3) [17][18]; although this does not affect conclusions about direction and relative magnitude, it should be acknowledged as an approximation. Second, rider observations are subjective; future work should pair them with instrumented data (e.g., AFR, in-cylinder pressure, and regulated emissions) to triangulate causes of transient hesitation.

As summarized in Table 2, the visual progression of combustion-chamber deposits was already apparent as early as 20 hours of operation, with thin films and early yellowing of the piston crown being observed. By 40 hours, the chamber exhibited a darker appearance with thicker accumulation, particularly near the dry-valve region, though the distribution remained relatively uniform. At 50 hours, deposits became heavier and covered larger areas of the piston and chamber surface, but the deposits were still controlled and did not critically impede surface function. These observations provide important context for the quantitative measurements at 110 hours, showing that deposit formation begins early but intensifies significantly between 40–50 hours, reinforcing the need for longer endurance testing.

Table 3. Rider-reported observations during durability testing

Condition	Key Observation
Standard (No Treatment)	No hesitation; light throttle response; no overheating; climbed hills (Sitinjau Lauik, Universitas Andalas, UIN Campus 3 Sungai Bangek) without difficulty.
Treatment 1	Occasional brief hesitation (<1 min) when fuel gauge near “E” after 3–4 h of riding; slightly harder morning starts (3–4 s crank); no overheating; hill-climb performance remained good.
Treatment 2	Early phase (20–40 h): hesitation under >140 kg load on steep grades; low power at start despite wide-open throttle; required 3–5 min to reach high-rpm power. By 50 h, performance stabilized and hill climbs with >140 kg load was successful; no overheating reported.

The rider-reported observations further contextualize these findings, as summarized in Table 3. Under standard conditions, the motorcycle exhibited stable drivability with no hesitation, smooth throttle response, and the ability to climb steep grades without overheating. However, with Treatment 1, occasional minor drivability issues were reported, such as brief hesitation when the fuel gauge was near empty and slightly harder starting after extended operation. Importantly, these issues did not compromise overall hill-climb performance or thermal stability. Treatment 2, in contrast, showed more noticeable drivability trade-offs in the early phase (20–40 hours), including hesitation under heavy loads (>140 kg) and delayed achievement of high-rpm power. Nevertheless, by 50 hours, the performance stabilized, with successful hill climbs and no overheating reported. These results highlight the calibration challenges when modifying ignition timing, where improvements in deposit reduction must be balanced against transient drivability effects during early operation.

From an applied engineering standpoint, Treatment 2 represents the most effective configuration for enhancing engine durability through the regulation of combustion-chamber carbon deposits. By limiting the accumulation of deposits, it facilitates cleaner and more stable combustion, reduces the formation of hot spots and abrasive scaling, and consequently diminishes the probability of component damage. The inferences drawn align with the quantitative discrepancies presented in Table 1 and the temporal progression illustrated in Table 2. Furthermore, the rider feedback documented in Table 3 underscores a pragmatic trade-off: early-phase drivability penalties occurring even under optimal chamber conditions. Addressing this trade-off will likely necessitate the implementation of closed-loop electronic control systems that dynamically adjust ignition timing and optimize fuel delivery in real time, taking into account variables such as load, temperature, and air-fuel ratio. This approach aims to ensure that the benefits of durability are achieved without sacrificing ride comfort.

The findings significantly advance the development of bioethanol-based alternative fuel technologies specifically tailored for small spark-ignition engines. The integration of a programmable ECU, an iridium spark plug, and a bioethanol–gasoline blend effectively supports emissions-reduction objectives while also offering the potential for reduced long-term maintenance expenses through the mitigation of carbon-deposit buildup. The findings collectively endorse a shift towards environmentally sustainable vehicle technologies, aligning with principles of energy efficiency and the rationale of a circular economy [19][20][21].

Conclusion

This study evaluated three engine configurations on a four-stroke motorcycle: Standard (no modification), Treatment 1 (iridium plug; 350° injection; 5° ignition; 70% Pertalite–30% ethanol), and Treatment 2 (iridium plug; 350° injection; 9° ignition; same blend) over 110 operating hours. Endpoint measurements demonstrated a clear and monotonic reduction in combustion-chamber deposits from Standard to Treatment 2. Deposit mass decreased from 680 mg (Standard) to 250 mg (Treatment 1) and 150 mg (Treatment 2), while volume fell from 378 mm^3 to 138 mm^3 and 83 mm^3, respectively. Thus, Treatment 2 delivered the strongest effect, reducing deposits by ~77.9% (mass) and ~78.0% (volume) relative to Standard, and also outperforming Treatment 1 by ~40% (mass) and ~39.9% (volume). Visual inspections at 20, 40, and 50 hours reinforced these results, showing the cleanest piston crown and chamber surfaces under Treatment 2. Collectively, the findings confirm that the combination of a programmable ECU (with optimized ignition advance), an iridium spark plug, and an E30 fuel blend promotes cleaner combustion, slows carbon-deposit accumulation, and enhances engine durability. Although early-phase drivability penalties were observed under Treatment 2, these diminished after ~50 hours, indicating calibration sensitivities rather than fundamental limitations of the configuration. Future studies should focus on closed-loop calibration strategies to eliminate these early drivability issues while retaining the chamber-cleanliness benefits. Practically, this will involve adaptive fueling and ignition control with AFR feedback (e.g., wideband oxygen sensing) and load-/temperature-based spark scheduling, using the 350° injection / 9° ignition map as a baseline.

Ultimately, this research advances the practical application of bioethanol–gasoline blends and programmable ECU tuning as a viable pathway toward more durable, cleaner, and environmentally sustainable small spark-ignition engines.

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