CHARACTERIZATION OF SPARK PLUG ELEMENTS USED IN SPARK IGNITION ENGINES

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In the current global context, research conducted in recent years on internal combustion engines has focused on improving their environmental performance. In this regard, special attention is given to the ignition system and its components, particularly the materials used in the construction of the system. This paper presents the analysis and tests conducted in the laboratory concerning a batch of spark plugs with specific construction characteristics depending on the type of internal combustion engine they are used for. Topographic and morphological analyses were carried out on the samples taken from the components of the studied spark plugs.

Keywords: internal combustion engine, ignition system, spark plug, environment.

1. Introduction

In a spark-ignition engine, the combustion process is initiated by an external thermal source, which ignites the compressed fuel mixture composed of air and gasoline vapors at a well-defined moment. Ignition occurs due to the appearance of an electric spark between the electrodes of a spark plug placed inside the combustion chamber. Ensuring a reliable and consistent ignition for each engine cycle, under any conditions and at any operating regimes, is essential to avoid misfires and faulty engine operation. Misfires lead to [1,2]: incomplete combustion, deterioration or even destruction of the catalytic converter, high pollutant emissions, increased fuel consumption, and reduced engine power and torque. The spark plug provides the necessary energy for fuel ignition in the combustion chamber, energy generated by the induction coil. The high voltage applied to the spark plug electrodes generates an electric spark between these electrodes, a spark that will trigger the ignition of the fuel mixture [3,4,5]. The spark plug is exposed to variable processes occurring inside the combustion chamber, as well as external climatic conditions. A spark plug activated by an electronic system can withstand voltages up to 30,000 V. Under these conditions, the ceramic insulator of the spark

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plug must be capable of preventing flashovers (accidental discharges in the form of short circuits) and thus misfires, as well as avoiding cracks. These properties of the insulator must be maintained throughout the entire service life of the spark plug, even at operating temperatures of up to 1000°C. Mechanically, the spark plug is subjected to periodic pressure of up to 100 bar from the combustion chamber, and the sealing must be perfect. The portion of the spark plug that enters the combustion chamber is exposed to a chemical process at very high temperatures, which is why the materials used must have high resistance to chemical attack. The sudden temperature variations in the combustion chamber (from high values during combustion to low values corresponding to the fresh fluid) demand increased resistance of the ceramic insulator material to thermal shock [4,6,7].

The electrodes are generally made from nickel alloys, the insulator is made from alumina-based ceramic materials, and the casing is made from steel. Recently, precious metals such as iridium, silver, gold, and platinum have been increasingly used in the manufacture of electrodes, as they have superior properties compared to traditionally used materials [8,9]. Since the lower part of the insulator is in the combustion chamber, high-purity alumina with superior characteristics such as heat resistance, mechanical strength, excellent insulation, and high-temperature thermal conductivity is used [10-15]. Depending on the type of material of the central electrode, there are iridium, yttrium, tungsten, platinum, and palladium spark plugs [16,17]. Iridium automotive spark plugs are considered the most durable and wear-resistant, used in high-power engines, but when installed on conventional engines, they do not create significant improvements. When choosing a spark plug, special attention should first be given to the material from which the central electrode is made (in cheap spare parts, iron, nickel, copper, or zinc can be used for its manufacture).

2. Laboratory tests

The paper presents the tests and analyses conducted in the laboratory and the results concerning a batch of seven spark plugs with specific construction characteristics depending on the type of internal combustion engine they are used for. For the tests conducted in the laboratory to analyse the spark plugs (specific characteristics, architecture, and defects), the educational kit shown in Fig. 1 was used [7]. This kit was created at the Faculty of Engineering Hunedoara in collaboration with the CorneliuGroup Research-Innovation Association as part of the "DEXTER" Laboratory program [8]. The following were identified in the laboratory analyses: non-conforming distance between the central electrode and the side electrode, electrode coverings with soot/carbon deposits, cracks in the external ceramic insulator, wear on the central electrode, partially melted electrodes, damaged threads, and fractures in the ceramic layer. In the first phase, the characteristics of the spark plugs were determined, and then their defects were identified.

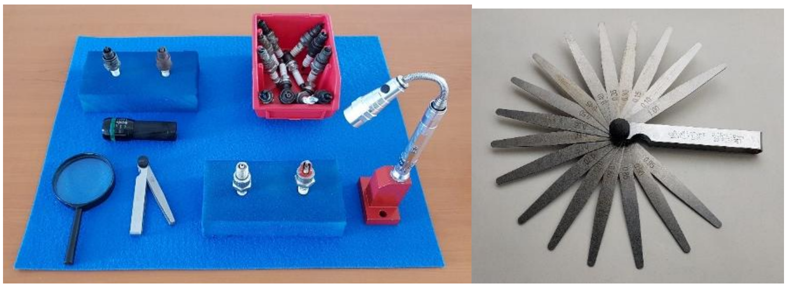


Fig. 1. Spark Plug Analysis Educational Kit

In the first stage, the characteristics of the spark plug were determined: brand/code, architecture (dimensions), number of side electrodes, and heat value. Based on the brand and code of the spark plug, the specific distance between the electrodes was determined, the thread dimensions (diameter/length) and hexagon size were established, and the type of spark plug was classified according to the number of side electrodes. Then, the dimensions of the central electrode were analysed, and the heat value of the spark plug was determined. In the second stage of the tests, the defects were identified by following these steps: the spark plugs were mounted on the study support, measurements of the electrode distance were taken using feeler gauges for spark plugs with one side electrode, and the components of the spark plug were analysed to identify the defects. The aspects from the tests conducted are presented in Fig. 2.

Fig. 2. Aspects from the tests conducted.

A batch of seven spark plugs with the following construction characteristics was subjected to experimental tests (fig. 3): B1 – spark plug with one side electrode;

B2 – spark plug with two side electrodes; B3 – spark plug with three side electrodes; B4, B5 – spark plugs with four side electrodes; B6, B7 – spark plugs with one side electrode (Denso Iridium [16]). A stereomicroscope was used to analyse the evolution of electrode wear on the spark plugs.

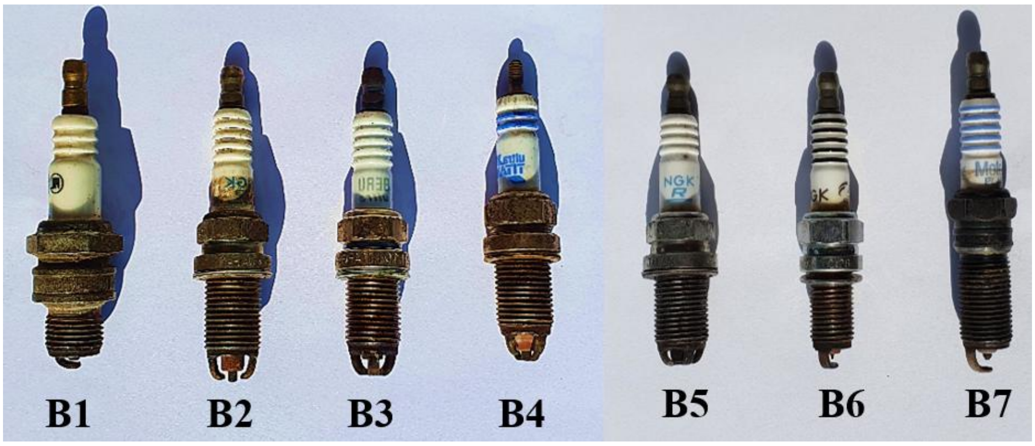


Fig. 3. Batch of spark plugs subjected to experimental tests

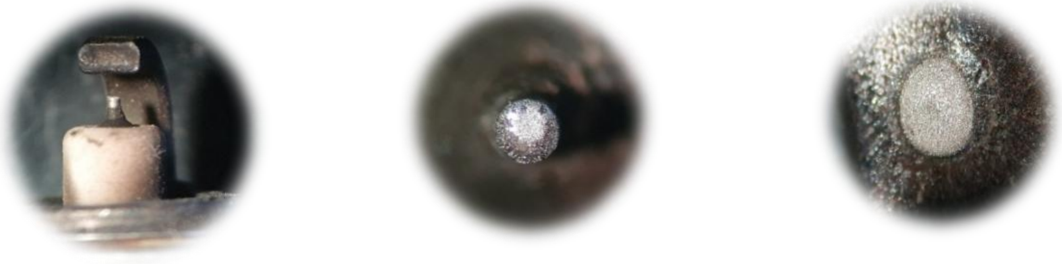
A stereomicroscope was used to analyse the evolution of electrode wear on the spark plugs. The aspects identified in the batch of analysed spark plugs are presented in figures 4-7.

a b c

Fig.4. Deposits:

a - spark plug with one side electrode; b - spark plug with two side electrodes;

c - spark plug with three side electrodes



a b c

Fig. 5. Denso-Iridium Spark Plug

a - between iron; b - central electrode; c - side electrode

a b c

Fig. 6. Spark plug electrode wear

a - between iron; b - central electrode; c - side electrode

a b c

Fig. 7. Iridium central electrode

a - frontal part; b - layered section; c - copper core

Subsequently, tests were conducted on the materials of the central and side electrodes, which required their extraction through cutting (fig.8).

Fig. 8. Samples for topographic and morphological analysis

The extracted samples were analysed for the purpose of performing topographic and morphological analysis at the Institute for Research in Renewable Energies in Timișoara.

3. Result and discussion

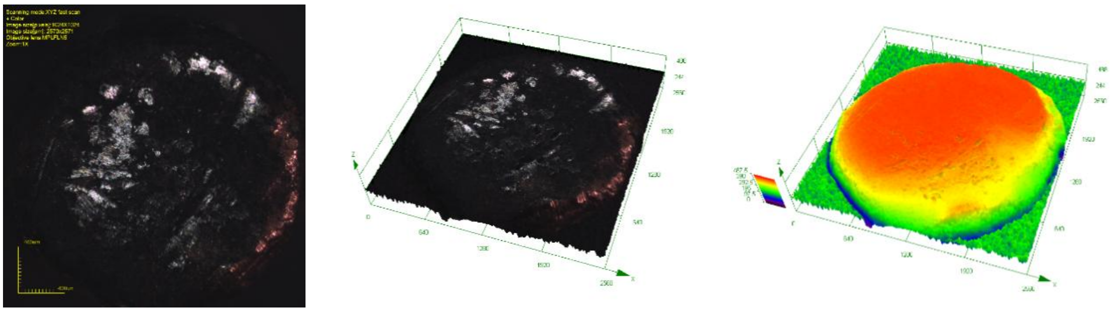
Topographic and morphological analysis of samples taken from the experimental batch of spark plugs was performed using the Olympus OLS 4000 LEXT confocal laser 3D microscope and the Quanta FEG 250 microscope equipped with an EDAX analyser and Apollo SDD detector.

Figures 9 – 22 present captures taken with the Olympus confocal laser 3D microscope, as follows:

a – electrode photograph (zoom: 1X);

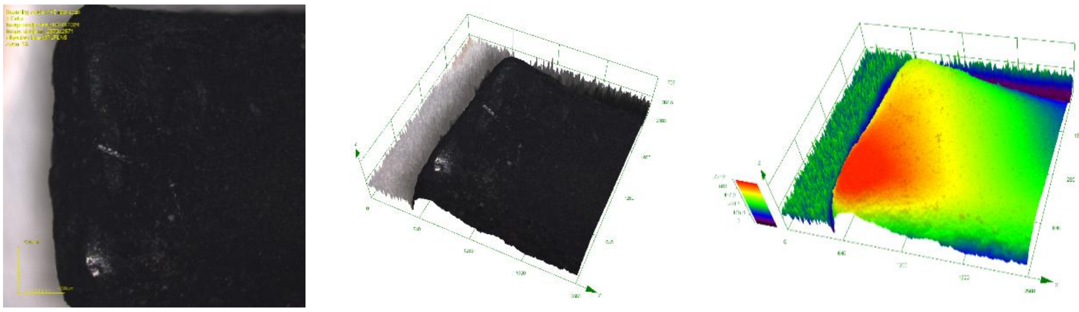
b – topographic analysis of the surface;

c – highlighting the height irregularities



a b c

Fig. 9. B1 Central electrode



a b c

Fig. 10. B1 Side electrode

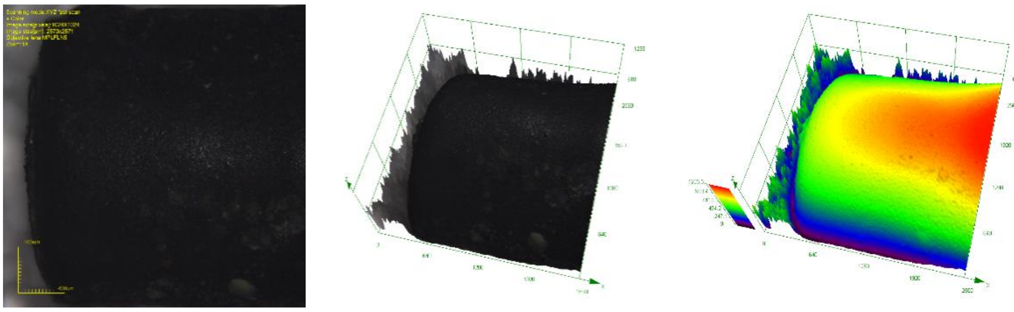


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Fig. 11. B2 Central electrode

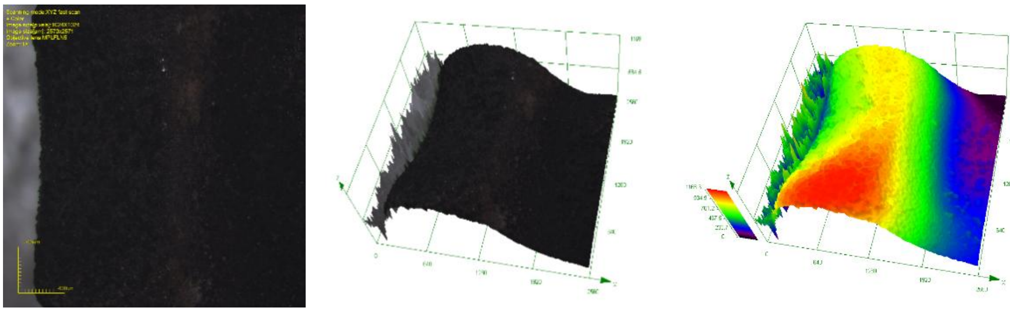

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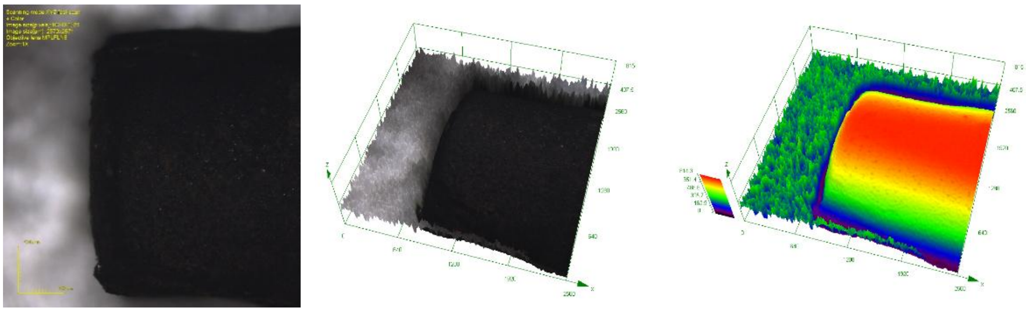
Fig. 12. B2 Side electrode



a b c

Fig. 13. B3 Central electrode

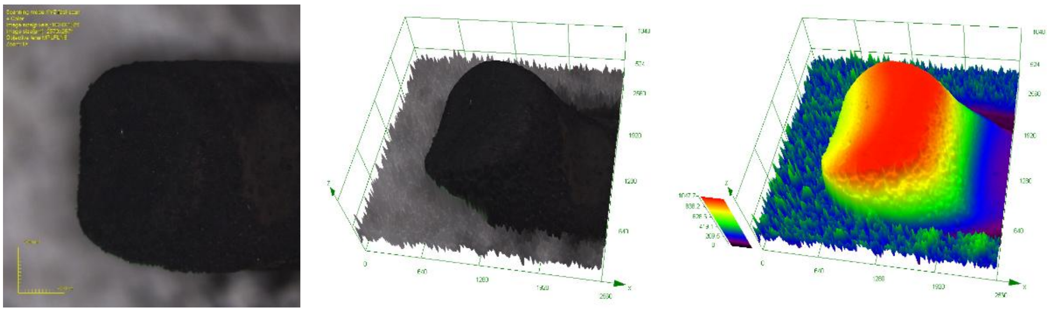


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Fig. 14. B3 Side electrode

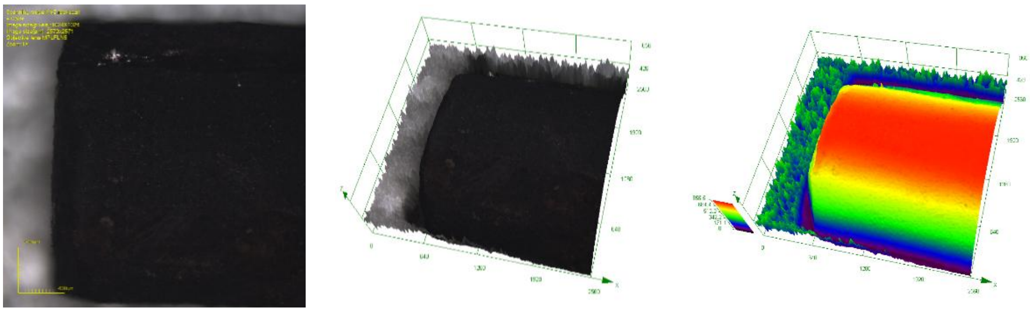

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Fig. 15. B4 Central electrode

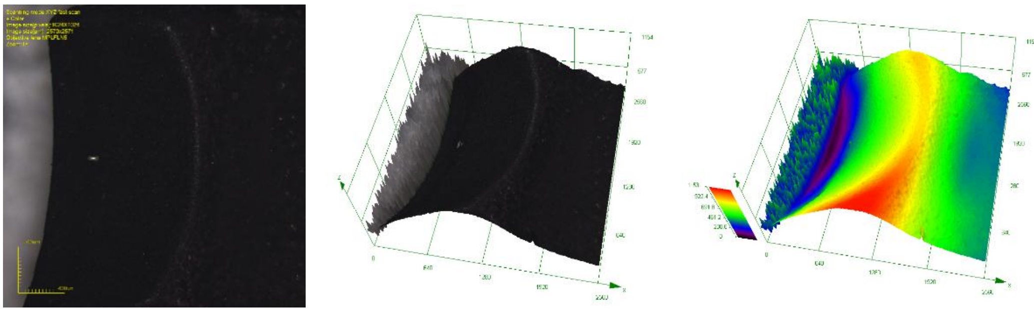

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Fig. 16. B4 Side electrode

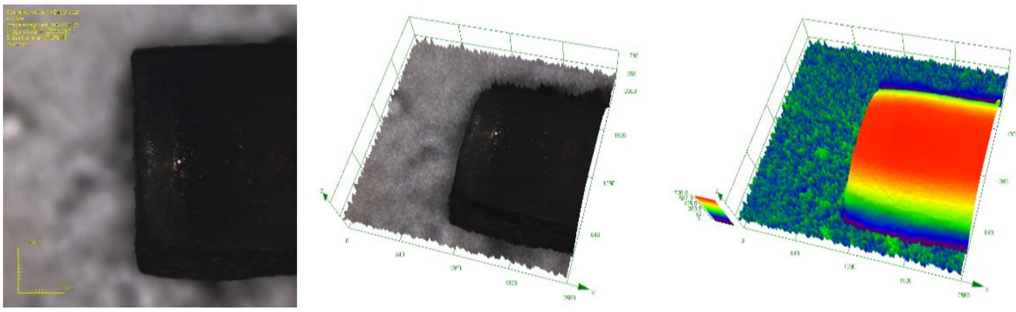

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Fig. 17. B5 Central electrode

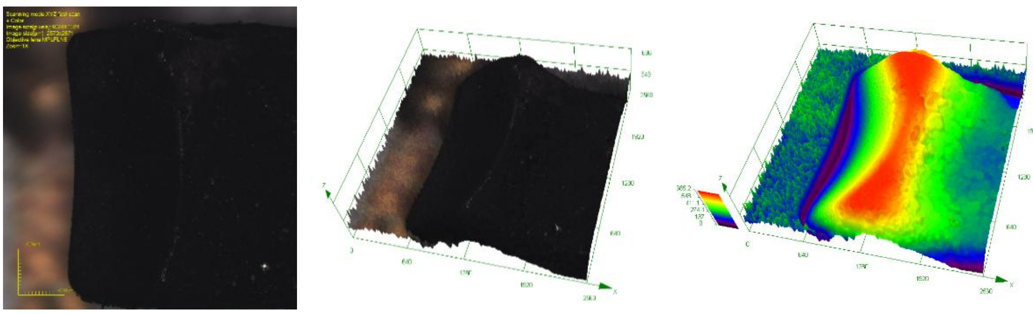

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Fig. 18. B5 Side electrode

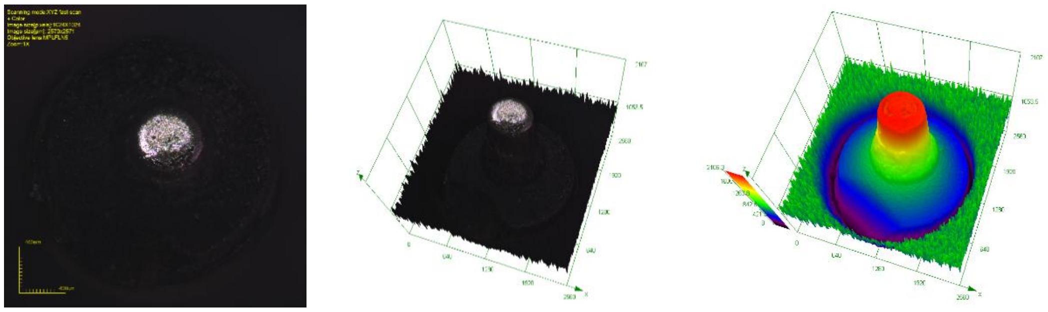

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Fig. 19. B6 Central electrode

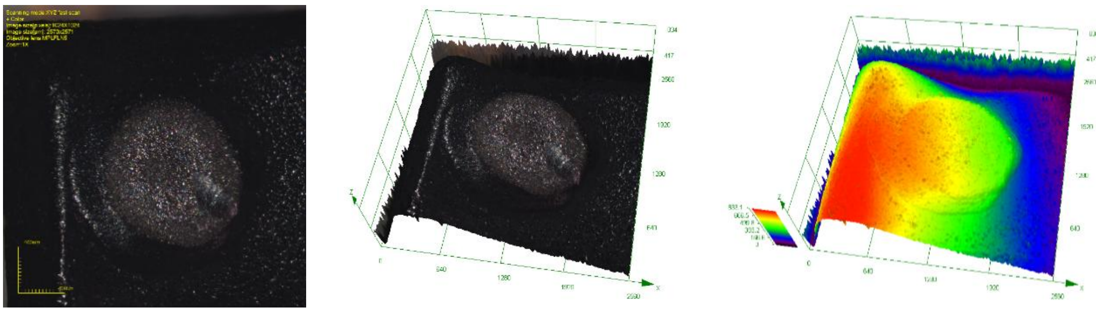

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Fig. 20. B6 Side electrode

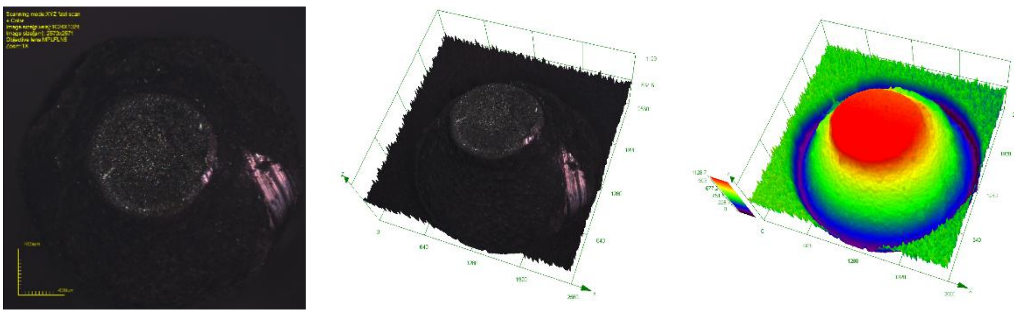

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Fig. 21. B7 Central electrode

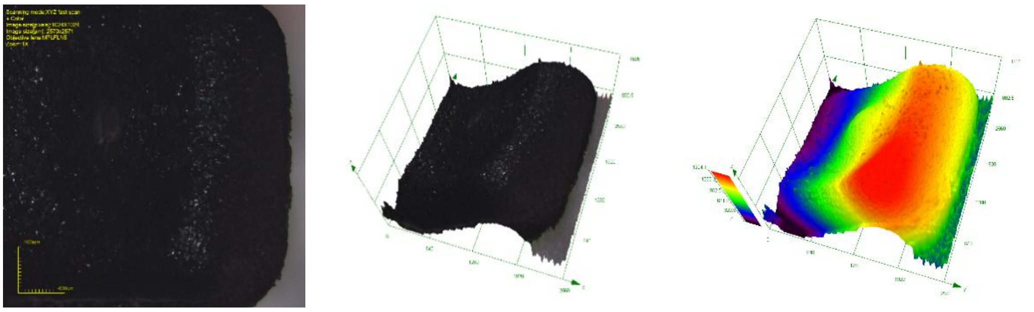

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Fig. 22. B7 Side electrode

Through topographic analysis, the wear due to the spark formation process and combustion process is highlighted, which stresses the front and side surfaces of the spark plug electrodes. Figures 19-22 present the topographic analysis of the central and side electrodes of Denso Iridium spark plugs installed on a 1.4L cylinder capacity engine of a Ford Puma vehicle.

From the analysis conducted, pronounced wear is observed in the case of sample B7 as a result of non-conforming engine operation due to the presence of coolant inside the engine cylinder, caused by a crack in the cylinder head combustion chamber.

The operating duration of the spark plugs from which the samples were taken is 25,000-29,000 km, whereas the manufacturer guarantees an average duration of 60,000 km.

4. Conclusions

The spark plug operates in a corrosive atmosphere, often at very high temperatures, and the electrodes are subjected to a wear process that leads to an increase in the breakdown voltage. When the breakdown voltage value can no longer be provided by the induction coil and ignition system, misfires occur. Impurities, as well as excessive oil consumption due to engine wear, can also affect spark plug operation. Consequently, pollutant emissions increase, potentially leading to damage to the catalytic converter. Therefore, spark plugs need to be replaced at well-defined intervals. As a result of the wear of the spark plug electrodes material, the distance between them increases proportionally with the spark plug's service life. There are two causes responsible for this wear: erosion caused by the spark and the corrosive environment inside the combustion chamber. To reduce the effects of electrode wear, heat-resistant materials such as platinum or platinum-based alloys are used. Additionally, wear can be reduced by choosing an appropriate electrode geometry and their relative positioning.

Abnormal engine operating conditions, such as detonation combustion and secondary ignition or auto-ignition, can cause irreparable damage to the engine in general and to the spark plugs in particular. Topographic analysis highlights the wear due to the spark formation process and the combustion process, which stresses the front and side surfaces of the spark plug electrodes.

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