

## AA35 – Morphological Studies on Spark Plug Grade Alumina for the Improvement of the Electro-Mechanical Properties of the Material

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### Abstract

Spark Plug is generally used in an internal combustion engine to produce a spark which ignites the air-fuel mixture in the combustion chamber. Basically, the key elements of spark plug are the shell, insulator, central electrode, and side electrode. The main part of the insulator is typically made by ceramic body that is produced with 92–95 % calcined alumina exhibiting desired properties like dielectric strength /constant which is governed by right quality alumina having desired morphology, particle size, specific surface area and impurity contents. The right combination of all these properties would lead to desired properties suitable for this specific application.

In the present study, all these properties were studied in detail to find out the suitability of alumina, with desired combination of properties. The development of required morphology was achieved through the combination of calcination process at a required temperature with the addition of a mineralizer having desired dielectric properties for these materials. Finally, a suitable alumina with roundish morphology and other required properties was found to be suitable to produce a high-performance product for this electro-ceramic application.

**Keywords:** Spark plug, electro-ceramic, calcined alumina, dielectric constant, roundish morphology

### 1. Introduction

Spark plug is an electrical device mainly used for internal combustion engines of automobiles. It ignites the compressed fuel mixture in the combustion chamber of the internal combustion engine. The role of the spark plug in IC engine is to deliver the electric charge from the ignition system to compressed fuel in the combustion chamber before the power stroke in the IC engine. Spark plug is shown in Fig.1, consists of various parts as central electrode, enclosed in ceramic insulator, and side electrode attached to the metallic shell. The insulators and central electrode can resist high combustion temperature. The reason is that heat must flow from insulator to metallic shell and after that it should go to the combustion chamber.

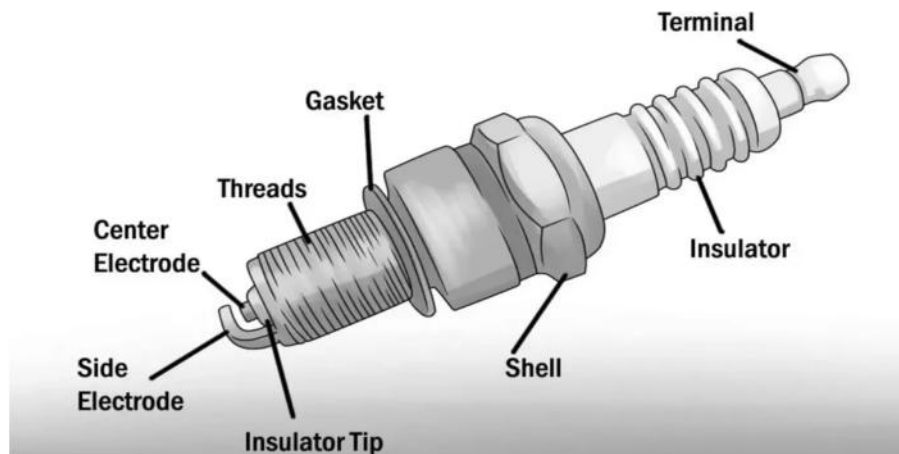


Figure 1. Image of spark plug [1].

The insulator is typically a ceramic material which is made from 92–95 % calcined alumina and the rest is flux made from clay, quartz, and feldspar to make sintered ceramic body to withstand elevated temperature and high voltage. It has good insulation capability even at a temperature of 1000 °C and can resist arcing & flashover. Dielectric strength or dielectric constant, volume resistivity, loss tangent etc. are the key properties of the ceramic material so that it can perform as an insulator in the spark plug. Calcined alumina is the major component of the ceramic insulator. Practically, these properties of the calcined alumina determine the quality of the ceramic insulator and its performance.

The properties of the alumina, like impurity content (soda, iron oxide etc.), microstructure or morphology (platy, flaky, roundish etc.), specific surface area, green density, fired density, porosity etc. are the major primary contributing factors of calcined alumina for exhibiting desired electrical – mechanical and dielectric properties of final ceramic body. Generally, hard calcined alumina with lower volatile material provides higher dielectric strength and higher volume resistivity and better insulating properties. Impurities, like sodium oxide create a low strength phase that leads to lower mechanical strength. It could also be noted that this mobile ion helps in dielectric breakdown that reduces the insulation capability of the material. Hence, it is a challenge to develop the required alumina having desired morphological structure and lower impurity with other required physio – chemical properties for designing the right kind of spark plug materials. Generally, roundish morphology with lower level of impurities, like  $\text{Na}_2\text{O}$ ,  $\text{Fe}_2\text{O}_3$  are suitable for spark plug application.

## 2. Conceptual Approach

Generally, calcined alumina is produced from the Bayer hydrate, through calcination at high temperature, along with other additive / mineralizer in the calcination process. Sometimes, hydrate is pre - calcined at lower temperature to increase surface area and then it is used as a feed for calcination. Mineralizer content, calcination temperature and feed material of calcination are the major variable parameters that can be controlled to get a desired alumina. The design of experiments was conceptualized using Taguchi orthogonal arrays model [2] to achieve the right kind of process condition for developing such type of alumina.

**Table 1. Taguchi orthogonal array model (L<sub>3</sub><sup>4</sup>) [3].**

Experiment Number	P1	P2	P3	P4	S <sub>N</sub> (signal -to – noise ratio)
1	1	1	1	1	S <sub>N1</sub>
2	1	2	2	2	S <sub>N2</sub>
3	1	3	3	3	S <sub>N3</sub>
4	2	1	2	3	S <sub>N4</sub>
5	2	2	3	1	S <sub>N5</sub>
6	2	3	1	2	S <sub>N6</sub>
7	3	1	3	2	S <sub>N7</sub>
8	3	2	1	3	S <sub>N8</sub>
9	3	3	2	1	S <sub>N9</sub>

### 3. Experimental

In this study, Aluminum tri-hydrate (ATH), partially calcined hydrate (PCH) and Smelter grade alumina (SGA) were used as feedstocks for producing alumina with different morphologies. The experiments were designed based on the Taguchi L<sub>3</sub><sup>4</sup> orthogonal array model. Two types of mineralizers (M<sub>1</sub>) and (M<sub>2</sub>) were also used to modify the crystal morphology of the alumina during calcination.

**Table 2. Four factors DoE to develop spark plug grade alumina.**

Trial No.	Factor 1	Factor 2	Factor 3	Factor 4
	Feed	Temperature (°C)	M <sub>1</sub> (%)	M <sub>2</sub> (%)
1	ATH	1450	1	1
2	ATH	1550	2	2
3	ATH	1650	3	3
4	PCH	1450	2	3
5	PCH	1550	3	1
6	PCH	1650	1	2
7	SGA	1450	3	1
8	SGA	1550	1	3
9	SGA	1650	2	1

Here, a total of nine experiments were conducted, using three types of feedstocks (Aluminum tri – hydrate, partially calcined hydrate, and smelter grade alumina). These feedstocks were mixed with the mineralizers (M<sub>1</sub> & M<sub>2</sub>) at different ratio. Then, the mixed samples were calcined in an electrically heated furnace at different temperatures (1450 °C–1650 °C) with an aim to develop an alumina with roundish crystal morphology having specific surface area in the range of 0.5–0.7 m<sup>2</sup>/g. The properties of the calcined alumina, generated during the calcination process are presented in Table 3. The crystal morphologies of the materials are presented in Figure.2. Subsequently, the alumina having desired crystal morphology, specific surface area and impurity

was selected to make the ceramic body in order to find out the performance of alumina for the spark plug application. The alumina of trials (6, 7 & 8) were milled using a Planetary mill at 30 rpm for 30 minutes. The resultant milled powders were mixed with flux using the pot mill and subsequently dried to produce the green bodies at 90 MPa. Then, green bodies were sintered in a muffle furnace at 1650 °C during 4 h and the fired density was measured using the well-known Archimedes principle. For Dielectric properties, samples of 50 mm diameter and 5 mm thickness were used. However, for wear resistance samples of 25 mm diameter and 10 mm thickness were used. Loss tangent, volume resistivity and dielectric strength were measured using LCR meter in the frequency range 1 KHz - 30 MHz as per the standard procedure.

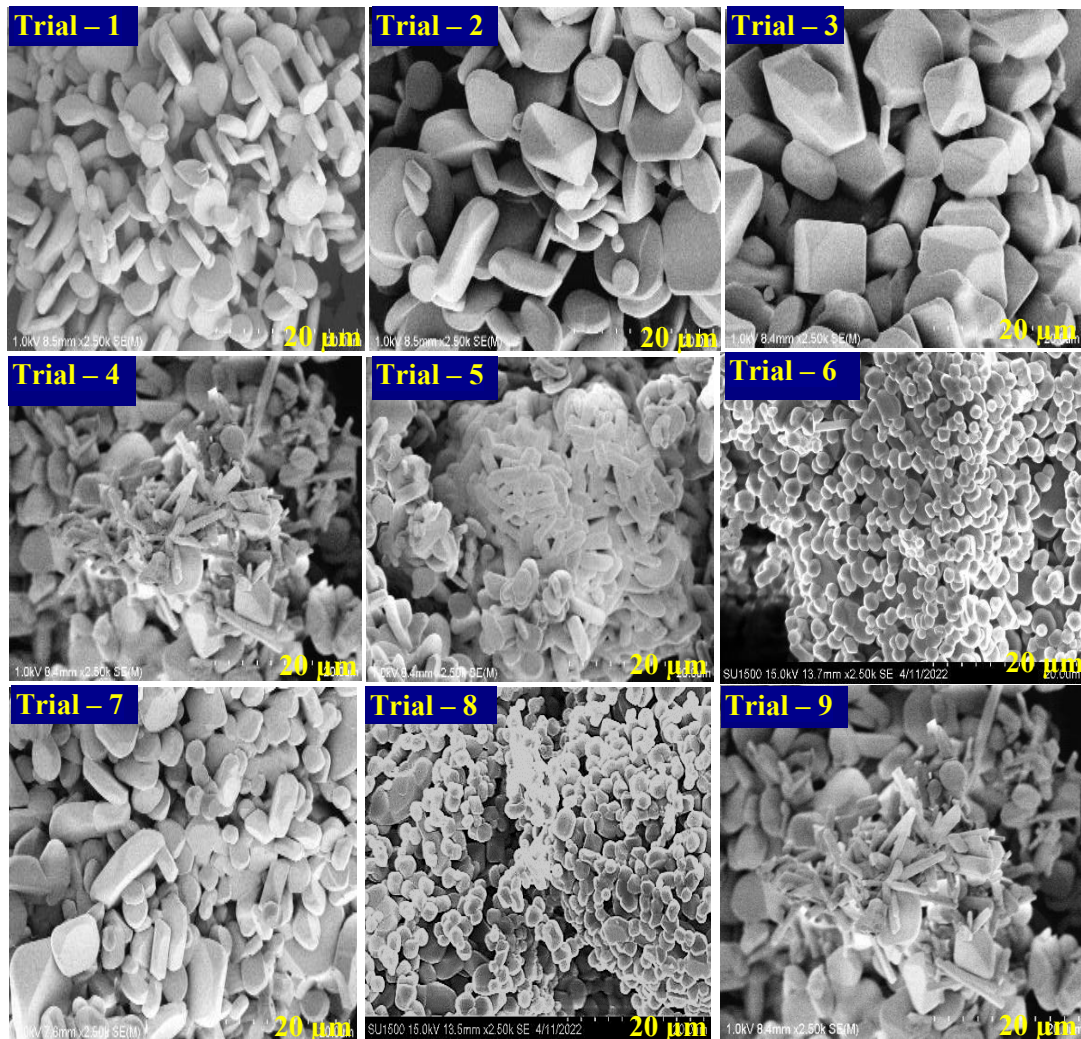
#### 4. Results & Discussion

The results obtained on the experiments (conducted through DOE) are presented in Table 3.

**Table 3. Physio – Chemical properties of calcined alumina.**

Trial No.	Chemical Properties							Physical Properties	
	Al <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	Fe <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	TiO <sub>2</sub>	CaO	SO <sub>3</sub>	SSA (m <sup>2</sup> /g)	Morphology
1	99.89	0.016	0.015	0.015	0.005	0.045	0.017	0.75	Platy
2	99.90	0.014	0.014	0.015	0.005	0.033	0.017	0.72	Platy
3	99.89	0.018	0.014	0.016	0.005	0.040	0.018	0.50	Platy
4	99.88	0.011	0.021	0.020	0.004	0.043	0.020	0.56	Platy & needle type
5	99.92	0.010	0.013	0.013	0.004	0.020	0.019	0.73	Platy & needle type
6	99.92	0.010	0.012	0.015	0.005	0.021	0.017	0.56	Roundish
7	99.90	0.013	0.021	0.015	0.004	0.024	0.019	0.65	Platy
8	99.90	0.013	0.021	0.018	0.005	0.025	0.019	0.62	Platy & partially roundish
9	99.88	0.010	0.020	0.020	0.004	0.052	0.018	0.68	Platy

It could be seen from the results that the products obtained from ATH feed stock showed higher Na<sub>2</sub>O content in general, compared to the feedstock of PCH and SGA. Overall, the PCH feedstock rendered lower soda level in the products. Generally, other impurities like Fe<sub>2</sub>O<sub>3</sub>, SiO<sub>2</sub>, TiO<sub>2</sub> & SO<sub>3</sub> are almost at a similar level for all the products. However, the CaO level shows a fluctuating trend.



**Figure 2. SEM morphology of alumina of the trials of DoE.**

Further, it could also be seen that a higher level of  $M_1$  mineralizer turned the alumina towards a platy shape. Of course, the combination of mineralizer and its calcination temperature should be considered for getting required specific surface area (SSA) and morphologies of the alumina which was also verified by repeated experiments. Normally, higher calcination temperature leads to a lower level of specific surface area, as could be seen from Table 3. Considering all these points in mind (lower level of impurities, desired SSA [4] with varying morphologies of alumina), trial number 6, 7 & 8 were selected for measuring electro – mechanical properties of spark plug body formulation, as presented in Table 4.

It could be seen from the results (Table 4) that the physical properties, like green density, fired density, porosity were almost in the similar range for all these selected aluminas. However, the dielectric properties (dielectric strength, volume resistivity, dielectric constant etc.) were on higher side for alumina with roundish morphology, compared to other types of morphologies. It could be seen from the results that effect of sodium oxide on morphology of calcined alumina is not visible since sodium oxide was in the lower range in the calcined alumina. The wear resistance of this type of alumina (roundish) is also better than the other materials (Table 4). Therefore, it could be said that lower level of impurities in alumina, having roundish morphology provides better dielectric and other required properties in spark plug body.

**Table 4. Electro - mechanical properties of ceramic, made from alumina.**

<b>Properties</b>	<b>Ceramic body, made from alumina of trial 6</b>	<b>Ceramic body, made from alumina of trial 7</b>	<b>Ceramic body, made from alumina of trial 8</b>
<b>Morphology of alumina</b>	<b>Roundish</b>	<b>Platy</b>	<b>Platy &amp; partially roundish</b>
<b>Mechanical properties</b>			
Green density, (g/cm <sup>3</sup> & 90 Mpa)	2.36	2.36	2.35
Fired density, (g/cm <sup>3</sup> @ 1650 °C/4 h)	3.7	3.7	3.7
Porosity (%)	0.1	0.1	0.1
Co-efficient of friction	0.66	0.64	0.62
Wear resistance, (mm <sup>3</sup> /N·m)	6.50 x 10 <sup>-05</sup>	6.02 x 10 <sup>-05</sup>	5.50 x 10 <sup>-05</sup>
<b>Electrical properties</b>			
Dielectric strength, (kV/mm)	8.73	8.46	8.67
Volume resistivity, (Ω·cm)	8.67 x 10 <sup>12</sup>	5.00 x 10 <sup>12</sup>	8.36 x 10 <sup>12</sup>
Dielectric constant	5.94	5.88	5.59
Loss tangent	0.001392	0.003385	0.00229

## 5. Conclusion

- ✓ PCH feedstock is found to be a better choice, compared to ATH & SGA, for producing the right kind of alumina for spark plug application.
- ✓ The right combination of mineralizers and calcination temperature is required for producing the right quality of material. The present study shows that M<sub>1</sub> & M<sub>2</sub> mineralizers with 1 % & 2 % addition respectively exhibit roundish morphology, when calcined at 1650 °C.
- ✓ This type of crystal morphology helps to provide better dielectric and wear properties, compared to other morphological aluminas.

## 6. Reference

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