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Implementation of sintered LTCC for the fabrication Of a 3D cylindrical Micro combustor

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ABSTRACT

The micro-combustor is a compact, sub-millimeter device that burns hydrocarbon fuels homogeneously as a source of power. It efficiently converts heat generated by combustion into electric power. We want to design a cylindrical structure, using the FemLab simulation program it demonstrates that doing this geometry can reduce impedance fluid, and several gas inputs can be placed under and several outputs can be placed around the mixing chamber so it can be more efficient.

The materials to be used for the construction of this device are fundamentally Low Temperature Co-Fired Ceramic (LTCC) and Graphite. The fabrication of this device will rely essentially on a thermal process (sintering of the LTCC tapes). The instruments that will be used for the fabrication include: a furnace for sintering the ceramics, a heated press for the ceramics lamination, a thermal laser and a numerically controlled milling machine for the patterning and machining of the tape. It is hoped that the combustor fabrication will be completed as designed. The parameters that characterize its combustion and power are expected to be consistent with its application as an electrical generator by means of the thermoelectric effect.

The main objective of this project is to complete the fabrication of a small combustor that contains fundamentally four inputs, four output, mixer and burning chamber. In two of its inputs a combustible gas (Propane) is injected, and oxygen from the air as an oxidizer flows through the other two inputs. The gases are mixed in the mixer area then goes to the burning chamber, a flame is initiated in the burning area to burn the fuel / oxidizer mixture.

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1. INTRODUCTION

When the air is mixed with a combustible and ignited to form a flame producing high temperatures, the process is known as combustion. The combustion is a chemical reaction in which a fuel (element or component) is combined with an oxidizer (generally oxygen in form of gaseous O_2), giving off heat and producing an oxide. Frequently used types of element for the combustion are the carbon and hydrogen. The combustion process happens as often in living beings as in devices used as sources of energy.

When this process happens inside a device, is known as a combustor. Combustors are commonly seen in mechanical motors such as in cars, airplanes, boats, etc. As one knows these are made to move and climb, as they are designed for the displacement of great weights that require enormous amounts of energy, which implies the consumption of great amounts of fuel. Nevertheless components exist that do not require large amounts of energy. These in their majority are electronics systems, which are designed to consume energy supplied by means of batteries and electricity.

To make a combustor at a small scale, one that will work for devices requiring lower energy levels, it has been proposed that one must construct a combustor of proportionally smaller dimension. This is known as a micro-combustor. The micro-combustor is a compact, millimeter length device that burns hydrocarbon fuels homogeneously as a source of power.

The main objective of this project is to complete the fabrication of a cylindrical micro-combustor out of LTCC tapes, which contains fundamentally four inputs, four outputs a combustion and a burning area. In the two inputs a combustible gas (probably propane) is injected, and air flows through the other two inputs. The gases are mixed in the mixer area. A flame is initiated in the burning area to burn the fuel / oxidizer mixture by means of a capacitor discharge or a piezoelectric element.

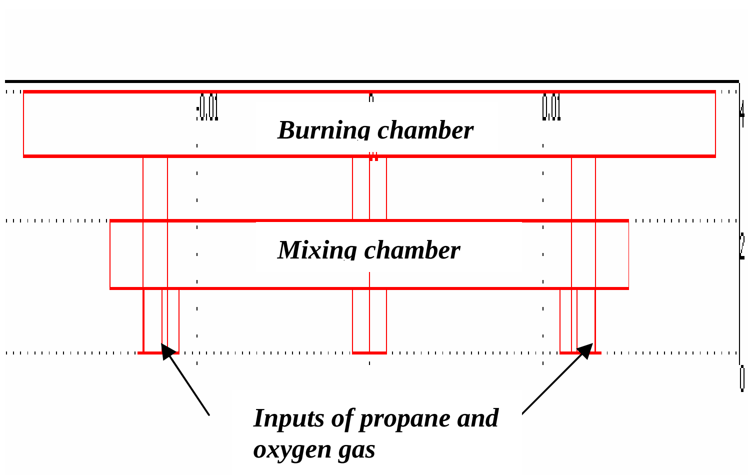


Fig1. Three-dimensional micro-combustor (on one side)

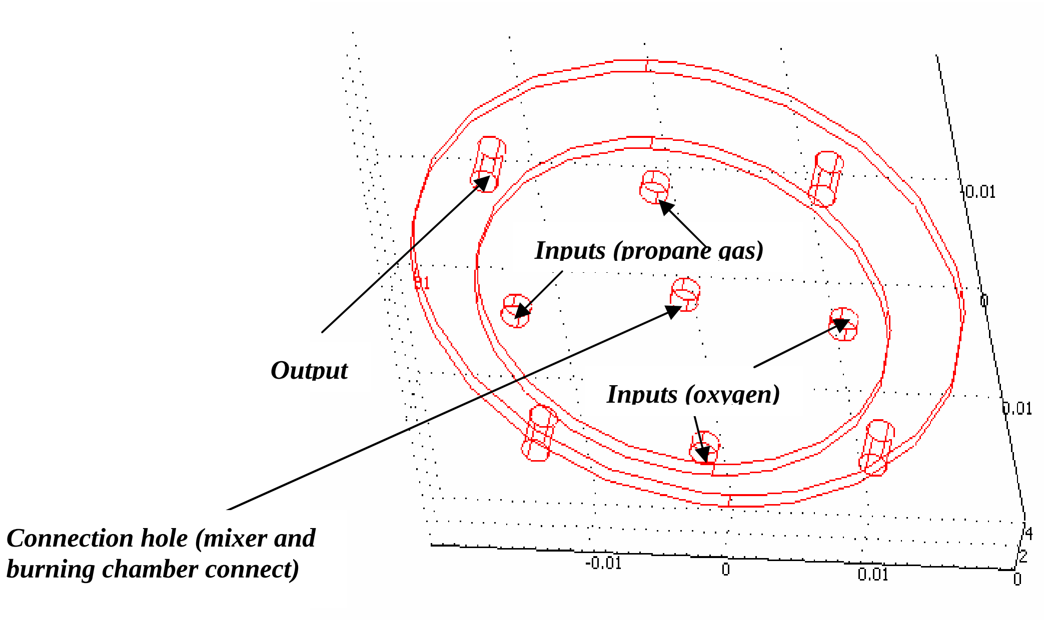


Fig2. Three-dimensional micro-combustor (on the bottom)

The materials to be used for the construction of this device are Low Temperature Co-Fired Ceramic (LTCC) tape. The LTCC represent an important alternative to be used as substrates for machining in the meso and micro scale. They provide several advantages including: electronic circuits can be integrated because of their hybrid nature, tapes of different compositions can be formulated to obtain desired layer properties (e.g. magnetic permeability), possibility of fabrication of hybrid structures consisting of ceramics, silicon, metals and/or some other suitable materials, layer count can be high, possibility of self-packaging, fabrication techniques are relatively simple, inexpensive and environmentally benign.

The fabrication of this device will rely essentially on a thermal process (sintering of the LTCC tapes). The instruments that will be use for the fabrication / characterization include: a furnace for sintering the ceramics, a heated press for lamination of the ceramics, and a thermal laser.

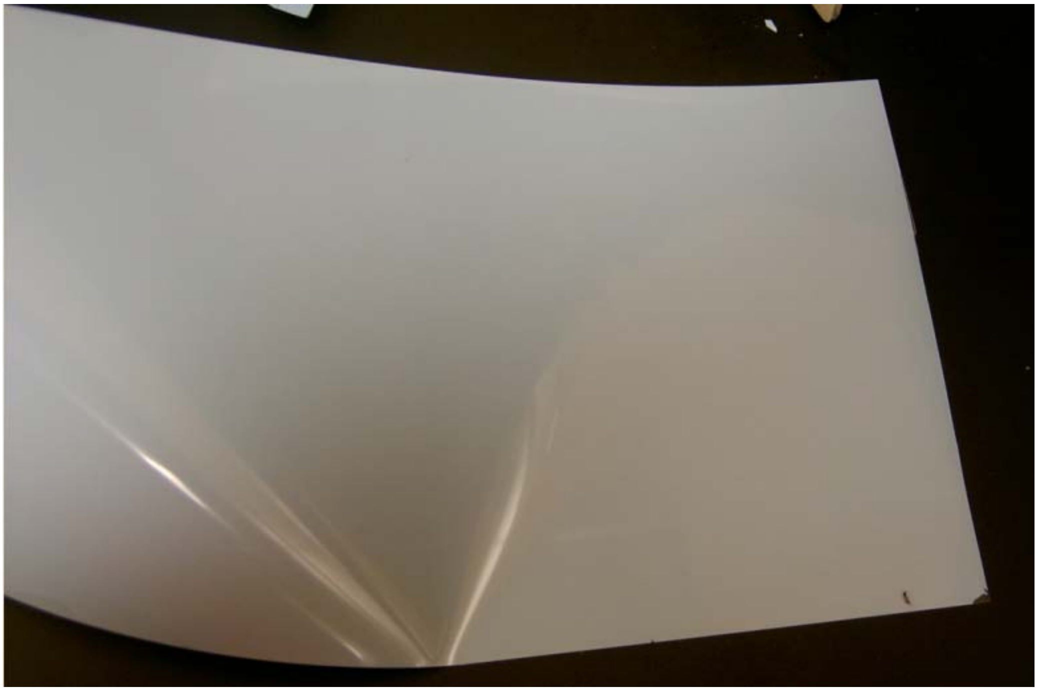


Fig3. Example of a LTCC Tape

2. BACKGROUND

The typical commercial battery has become the staple solution for portable power in today's society of mobile electronic devices. Unfortunately, current commercial batteries posses low energy density, short life spans, and are harmful to the environment upon disposal. The goal of the micro-combustor project is to combat the aforementioned disadvantages of the commercial battery by providing a competitive, portable energy sources.

A promising alternative to electrochemical batteries involves the combustion of liquid hydrocarbon based fuels. Since liquid hydrocarbon based fuels employ energy densities two orders of magnitude greater than commercial batteries, these fuels area able to provide an ideal source for mobile power generation. However, conventional methods of electrical generation require the combustion of hydrocarbons to drive a mechanical generator. The inclusion of the mechanical generator increases both the size and weight of such a system and reduces its efficiency due to intermediate energy conversions.

Unlike a conventional generator, the micro-combustor will harness the heat produced from combustion and directly convert it to electricity through a thermoelectric element. The absences of mechanical parts in a micro-combustor allows for a much smaller size and quiet operation while generating power. These features allow a micro-combustor to provide portable energy similar to a battery while allowing it to utilize greater energy density through hydrocarbon-based fuels.

Figure 4 shows potential energy of various sources in terms of energy density. Compared with liquid fuel such as gasoline, these alternative possibilities posses far smaller energy densities.

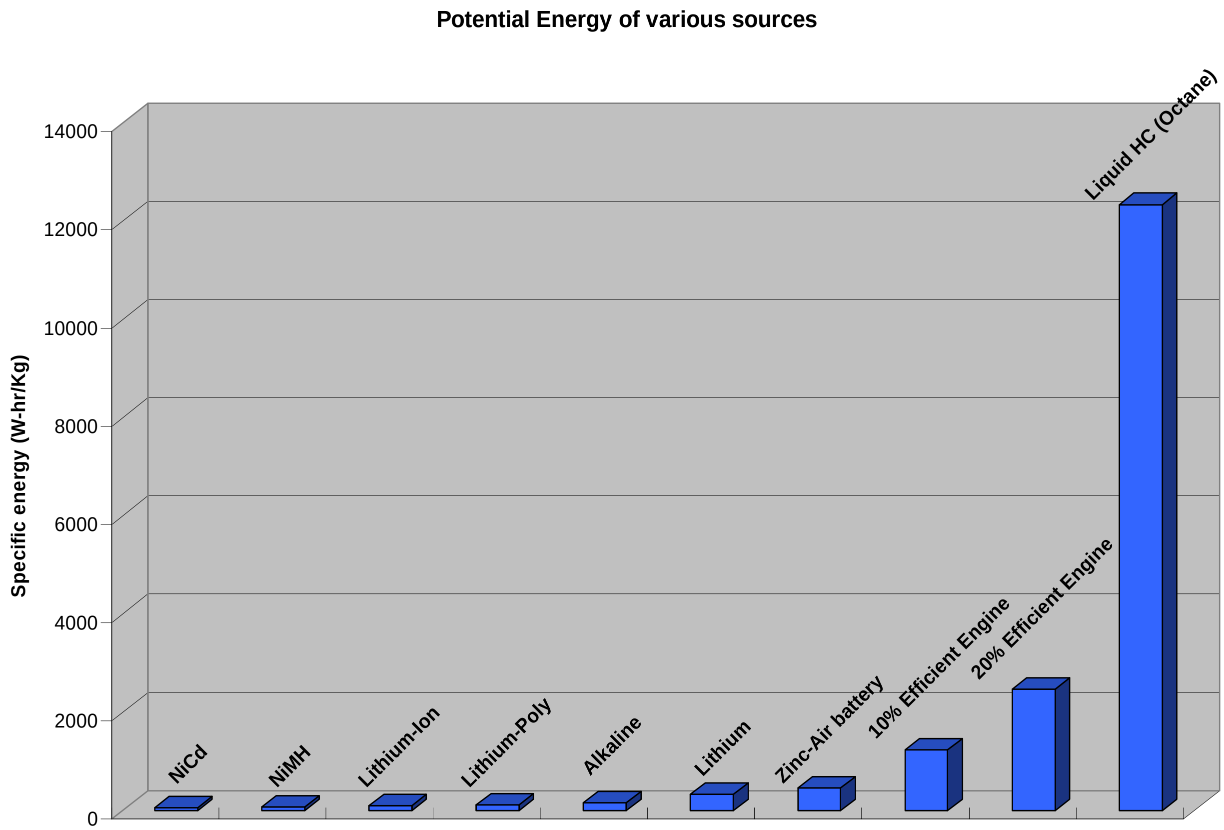


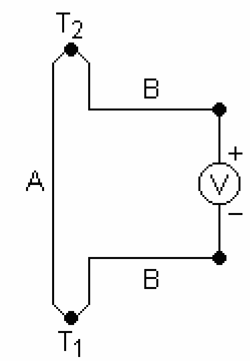
Fig4. Energy density of batteries in various forms

3. Theory

The theory behind the micro-combustor is largely summarized by the seebeck effect. The seebeck effect is a phenomenon, wich results in a voltage difference being produced across the terminals of an open circuit with each junction held at a different temperature. The produced voltage difference is directly proportional to the difference of the hot and cold junction temperatures and is not dependent on the distribution of temperature along the metal between the junctions. As result of the seebeck effect, the temperature gradient across the hot plate and the cold plate produces electric power.

A voltage, the thermoelectric EMF, is created in the presence of a temperature difference between two different metals or semiconductors. This usually causes a continuous current to flow in the conductors. The voltage created is on the order of several micro volts per degree of difference.

In the circuit:



(Which can be in several different configurations and be governed by the same equations), the voltage developed can be derived from:

$$V = \int_{T_1}^{T_2} \left(S_{\mathrm{B}}(T) - S_{\mathrm{A}}(T)\right) dT$$

S_A and S_B are the Seebeck coefficients (also called *thermoelectric power* or *thermopower*) of the metals A and B, and T_1 and T_2 are the temperatures of the two junctions. The Seebeck coefficients are non-linear, and depend on the conductors' absolute temperature, material, and molecular structure. If the Seebeck coefficients are effectively constant for the measured temperature range, the above formula can be approximated as:

$$V = (S_{\mathrm{B}} - S_{\mathrm{A}}) \cdot (T_2 - T_1)$$

Thus, a thermocouple works by measuring the difference in potential caused by the dissimilar wires. It can be used to measure a temperature difference directly, or to measure an absolute temperature, by setting one end to a known temperature. Several thermocouples in series are called a thermopile. This is also the principle at work behind thermal diodes and thermoelectric generators (such as radioisotope thermoelectric generators or RTGs) which are used for creating power from heat differentials. The Seebeck effect is due to two effects: *charge carrier diffusion* and *phonon drag.*

Materials and tools

The tools and materials utilized in the fabrication of these devices were:

1. Green tape type 951AT from Dupont, Delaware, PA, U.S.A (approximately 100 µm thick).
2. Isotemp Programmable Forced-Draft Furnace (Fisher Scientific)
3. Heated press (Carver Model C)
4. X-660 Laser Platform (Universal Laser Systems, Scottsdale, AR, U.S.A., 60 W CO_2 laser, wave length of 10.6 µm)

COMBUSTOR ARCHITECTURE

Below is a detailed description of the combustor morphology and configuration.

3.1 AUTOCAD2000i BASED ARCHITECTURE DIAGRAMS.

Below is a detailed scheme of the combustor architecture. Each layer has the measure of every space in the LTCC layer.

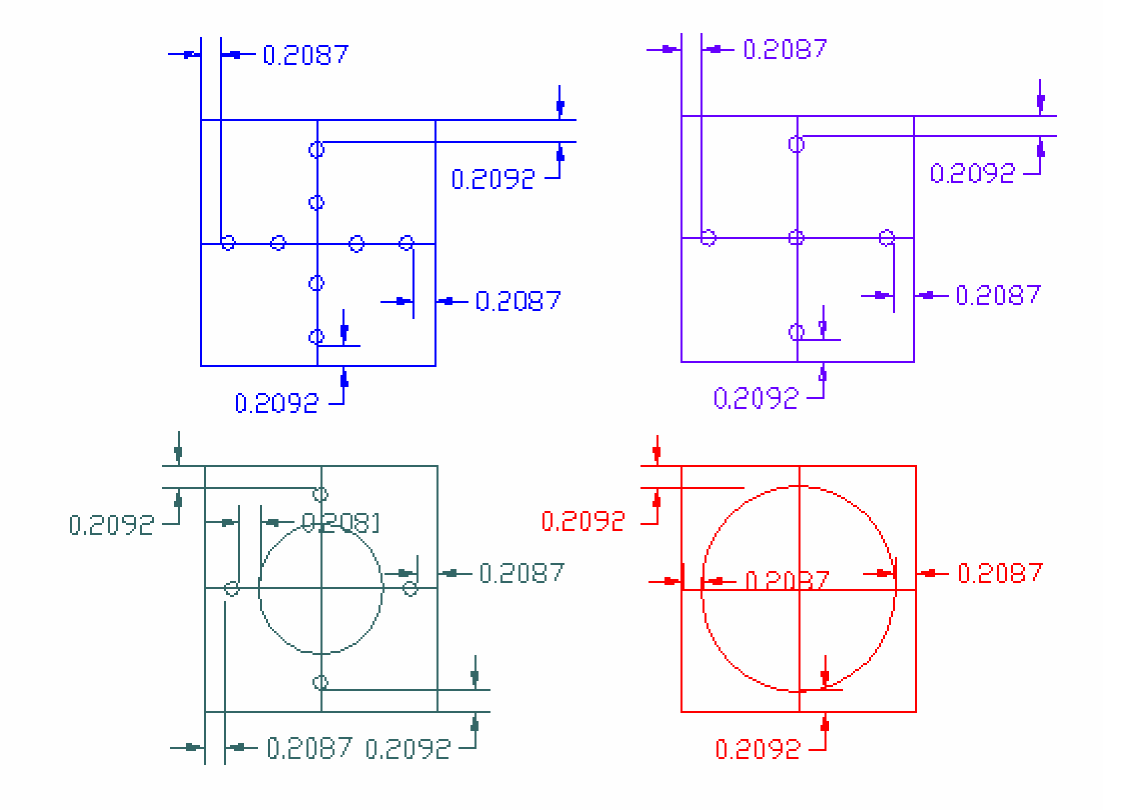


Fig5. Layers and measure of the layers in AutoCAD (Each layers is 2.4"x 2.4")

Layer Color	Circle diameter	Quantity of layer created
Blue layer	.0729” every circle	8
Violet layer	.0729” every circle	8
Green layer	.0729” the small circle and the bigger circle have .6391 “	23
Red layer	1.000”	23

Each layer has a different type of purpose and its build it in that way to have the cylindrical geometry we want to built. The idea of doing this geometry is because having several gas inputs and several outputs can reduce fluidic impedance so the efficiency of the micro combustor increases.

The blue layer it’s called the bottom layer, in this layer it’s were all the inputs of gas and oxygen goes. The violet layer it’s called the inter layer because it goes between the blue layer and the green layer, so its connect the outputs to the green layer and the hole in the middle it’s were all the mixture of the oxygen and the propane gas going to be passing trough the mixer chamber and finally goes to the burning chamber. The green layer it’s called the mixer layer because here is where all the gases are going to be mixing thanks to the design of the chamber. And the red layer it’s called the burning layer because here is where the device produces the flame thanks to the combustion process.

The following illustration show how the structure looks from the top, using AutoCAD layers.

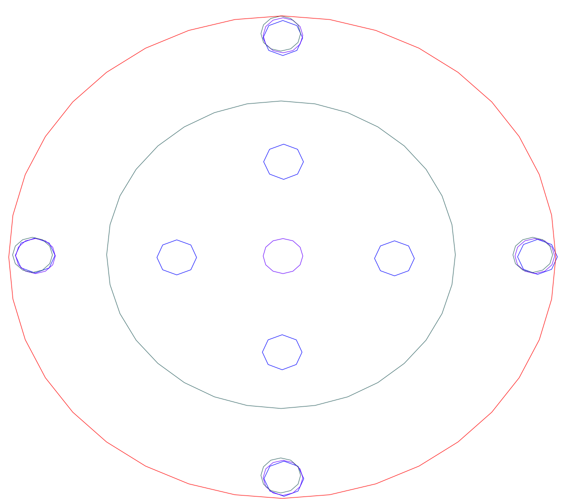


Fig6. Top part of the micro combustor using the auto CAD software

4. LASER PROCESS DETAIL

Before attempting the fabrication of the combustor, we calculated the number of LTCC tape sheets needed for the laminated structure. The DuPont 951 LTCC is about 4 mils thick (around 100 μm) and for one of the possible combustor inserts thickness (2mm), at least 50 layers were needed.

Fig7. X-660 Laser Platform

The X-660 laser platform makes the layer similar of the one that have been defined in AutoCAD. Spending some times putting LTCC layers in the machine and programming the laser to use a speed and power of 5%, this is how the layers look like:

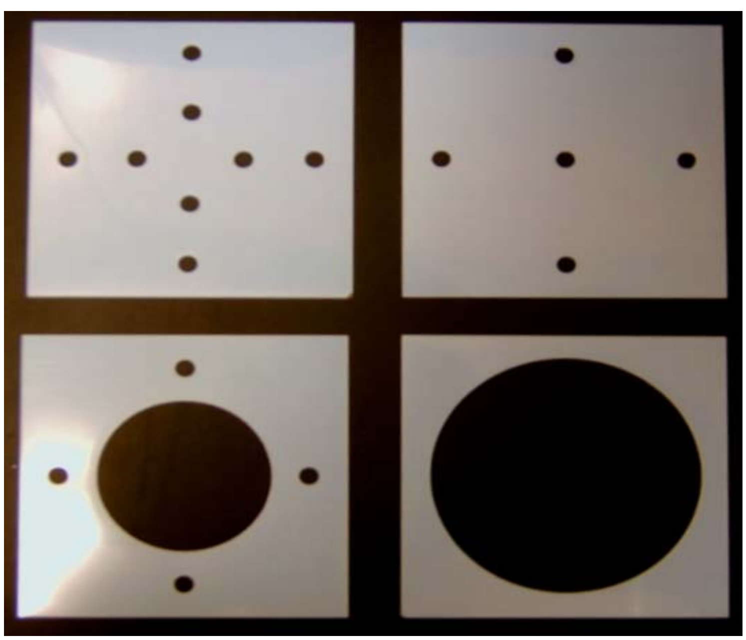


Fig8. Layers created using the laser printing process

4.1 Lamination Process

Lamination is the method or process utilized to bond all the LTCC tape sheets as to construct a monolithic 3-D structure upon heating under a stress. When laminating LTCC tapes, it is important to keep all the sheets consistently with the same side up, that is, the LTCC tapes are fabricated over a Mylar sheet. To facilitate the release of the LTCC from the Mylar, a lubricant is utilized. It is important that the "shinny" side (side facing the Mylar) is always up or down.

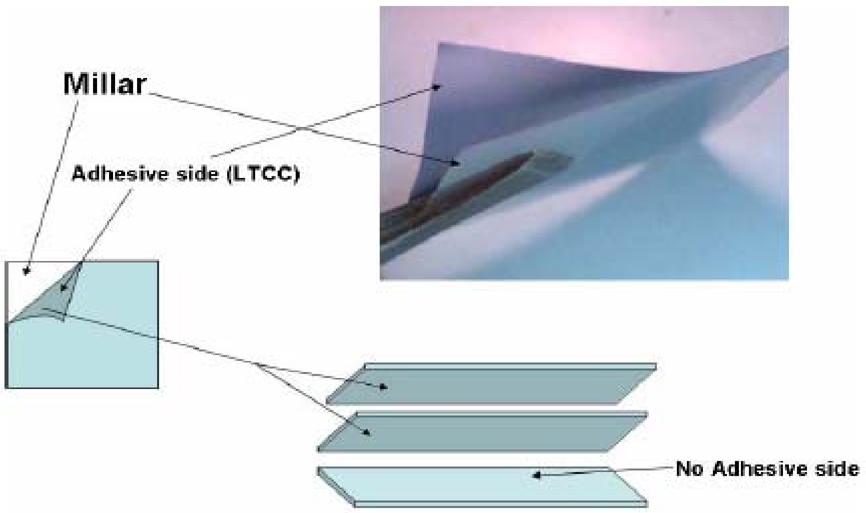


Fig.9 Consistent orientation of LTCC sheets before lamination.

The LTCC sheets at both ends of the laminate (top and bottom) are protected from the hot platens in the hydraulic press by Mylar sheets. During lamination, the stress and time are controlled for best results. In our case we laminated at 1000 psi for 20 minutes at a platen temperature of 80 C.

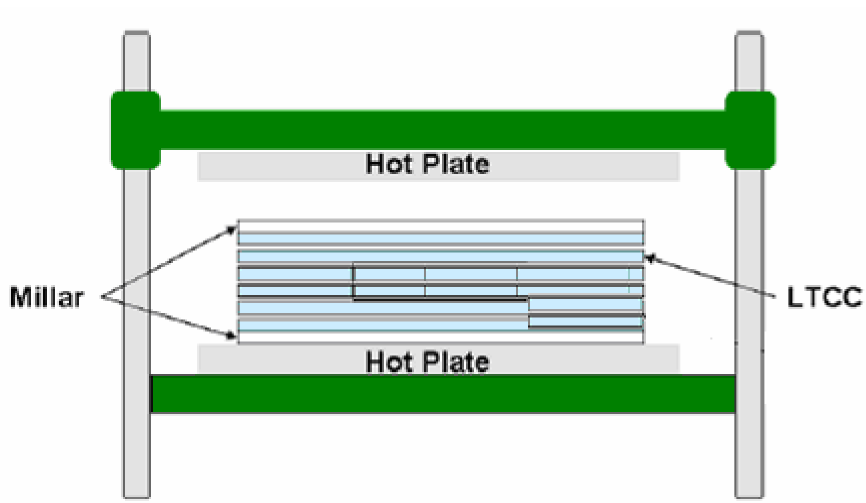


Fig.10 Scheme of the Lamination Process for the combustor using heated press (Carver Model C)

When we remove the structure we measure the thickness that was around .5mm using at least 50 layers and it looks this way when a picture from the top part was taken.

Fig.11 Top view of the micro combustor when the lamination process was done.

4.2 FURNACE PROCESS

The last process to do is putting the structure in a furnace. The heating schedule as programmed in the resistance furnace:

- From room temperature to 300º C at a rate of 10º C/min.
- Kept at 300 C for 30 minutes
- Ramp from 300 C to 850º C at a rate of 10º C/min
- Kept at 850º C for 1 hour and 45 minutes.
- Turn furnace off and let it cool to room temperature.

Doing this process can let the structure more rigid, harder and tight.

Fig11. Isotemp Programmable Forced-Draft Furnace (Fisher Scientific)

CONCLUSIONS

First we obtained that FemLab simulation show a better mixture of oxygen and propane gas in the 3D cylindrical micro combustor. In that way we improve the micro combustor compared for the one that have been done in the past. The process of design and build of this cylindrical micro combustor it is not too easy because the multiple layers and the four design in AutoCad it takes some times when doing the lamination process.

We learn too that the laser process can do the layers in terms of minutes. Using a 5% of speed and power we can obtain the four layer using LTCC tape. The dimension of the micro combustor was 2.5”x2.5” it can be improve to doing much smaller, but simulation and analysis have to be done to achieve this idea.

We don’t make any experimentation with this device because we don’t have much time left to do it, but as I said before simulation show a nice mixture of gases because the inputs and outputs the device have it. And it works more efficiency because it have different chamber to do the combustion process.

RECOMMENDATIONS

A good recommendations is to first do a lot of simulation using FemLab because in that way can see the effect of the mixture of the gases in the structure. Another one is to improve the dimension of the structure so it can be done smaller that the one we design.

Because we don't have much time left another good recommendation is to put graphite inside the structure so in that way when some one put the devices in the heat plates and in the furnace the LTCC can't break easily.

Last recommendation is to put some type of glue around the device so in that way it can prevent any gas leakage and can make the layers more stronger in that way.

ACKNOLEDGMENTS

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