RAPID MANUFACTURING OF A CHAMBER UTILIZED IN A MICROGRAVITY EXPERIMENT ABOARD THE INTERNATIONAL SPACE STATION

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Abstract. *Rapid Manufacturing is a powerful tool for facilitating the construction of experimental scientific systems. This is exemplified by the present work. A chamber was built utilizing Rapid Manufacturing to support an experiment of chemical reaction at microgravity aboard the International Space Station. In despite of the relevance of the experiment this work focuses the construction aspects of the chamber, in particular the mechanical aspects and corroborates the Rapid Manufacturing paradigm – building rapidly complex parts directly for final use at affordable costs. The chamber complexity is mainly due to the fact that it integrates mechanical, electrical and fluidic systems. One special issue was the lightweight material (porous polyamide) with which the chamber is made allowing that the total weight of the chamber was kept within the constraints defined by the space program managers. Selective Laser Sintering (SLS) was the Rapid Manufacturing Technology utilized to build the chamber in polyamide. We envision from this work an increase interest of applying Rapid Manufacturing not only for sending complex experiments to be performed in the International Space Station at low cost but also in a variety of experiments in differents research fields.*

Keywords: *Rapid Manufacturing, SLS, ISS, experiment in microgravity*

1. INTRODUCTION

1.1 Rapid Manufacturing Technology

Rapid Manufacturing (RM) is a production technology that allows building parts, rapidly and directly, for a final and definitive mechanical application, from 3D CAD models (Hopkinson *et all*, 2006). Its distinctive characteristic regarding the CNC technology is that it is capable to build parts having complex geometries that would be hard possible or even impossible to be built with CNC technology. This is because CNC is a subtractive technology while the RM is an additive technology allowing a greater freedom of forms. In the additive process the 3D CAD model is sliced and the resulting layers are physically built, stacked and bonded, simultaneously, from bottom to top, until the whole part is built. The addictive concept comes from the fact that the layers and ultimately the parts are built by agglutinating or arranging elemental structures such as grains, molecules and filaments. Making a parallel to the nanotechnology concept we would say that rapid manufacturing is a bottom-up (from powder to larger structures) process for construction meso, macro and, as has been shown more recently, micro size parts.

In general the RM has been related mainly to metals resulting in novel technologies being launched in the market, namely, Selective Laser Melting (SLM), Direct Metal Laser Sintering (DMLS), Laser Engineered Net Shaping (LENS) and Electron Beam Manufacturing (EBM). In this particular work we employ the RM concept to polymers once the polymeric parts are used to a final and definitive application that is a microgravity experiment. A Selective Laser Sintering (SLS) is the technology employed to build the polymeric parts and is explained in the next section.

1.2 Selective Laser Sintering – SLS

In the SLS technology (Fig.1), a CO_2 laser sinters together polimeric grains to build the parts. The grains agglutination process starts after a polimeric powder is arranged in a form of a layer (0.1 mm thick) on a region scanned by the laser which is called powder bed. In order to form the powder layer, the powder is spread and compressed by a roller along a platform in the middle of the which is situated the powder bed. On the powder bed the powder layer is heated to just below the melting point of the material to reduce the energy needed by the laser to sinter the material. Then the laser scans the region providing a temperature increment to sinter together the grains whereupon the part layer. Following the powder bed moves downwards to the interior of the build chamber creating a gap whose depth is equal to the layer thickness. This gap is filled with fresh unsintered powder forming the next layer to undergo the laser scanning. Similarly to the powder bed, the powder feeders are elevators which consist of plates mounted on top of pistons. The elevators bring an excess of powder to a position a bit higher than the platform expositing the powder to the roller. During the whole part building the powder feeders always move upwards while the powder bed move downwards and these movements occurs continuously and synchronically with the rolling movement and laser scanning. All these equipment components are kept in a nitrogen rich build chamber to reduce the explosion risk associated with fine powders. Also the part chamber where the part is growing by added layers is kept heated to avoid thermal stress and dimensional distortion. When the process finish the unsintered powder is removed to reveal the part. The remaining powder can be reutilized to make further parts till it looses its properties leading to an impoverishment of dimensional, mechanical and morphological properties. The SLS method of rapid manufacturing is a relatively quick method creating accurate and durable parts. The SLS drawback however is that the parts have a rather porous surface due to the sintering nature of the technology. But is some applications as commented below the surface porosity can be an advantage.

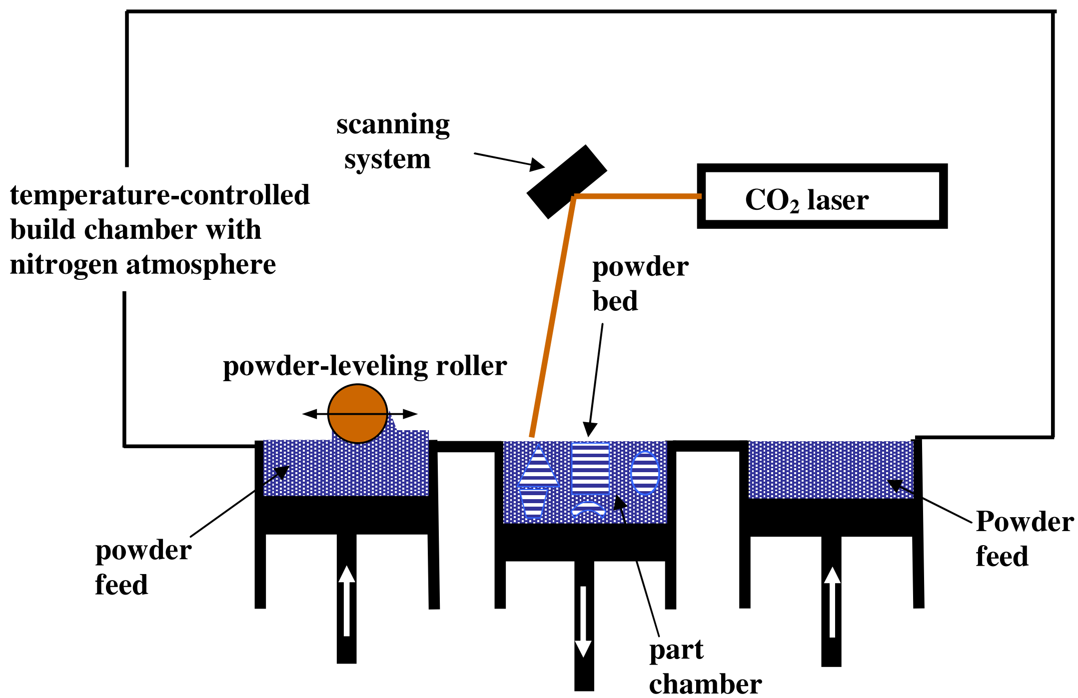

Figure 1. Diagram of a SLS equipment

1.3 Applications in scientific experiments

An important application domain of rapid manufacturing (RM) that has not been fully explored yet, according to a search work we made in the specialized RM literature and in the internet, is building complex systems to perform scientific experiments. This could be due to the fact that a considerable amount of the science people is not aware of the resources and opportunities that have emerged by the advent of RM in their particular areas of research. An evaluation of this could render an interesting work related to novel RM applications. We envision an increase contribution of RM in building simple and complex system for experimental research work because quite often the scientific experiments require special parts or devices that is not easily found in the market. Even though when they are found, time consuming and costly adaptations could be necessary. Besides circumventing these adaptations the RM, with its capability to generate free forms, could aggregate special features as, for instance, creating artifacts with fully integrated moving parts. To deal in a more general manner with the applications of RM for experimental scientific systems we have coin the expression Rapid Manufactured Scientific Experimental Systems (RMSES).

In our literature and internet search none RMSES was found related to operation in a microgravity environment. On the other hand there are reports of using RM to build parts for the International Station and the space shuttle fleet (Walter et al. 2004). A particular case that was divulgated concerns to a capacitor box fabricated in glass reinforced nylon with the SLS process (Spielman, 2006).

2. EXPERIMENTAL

2.1. Experiment General Description

Essentially the experiment consists of capturing the images generated by the luminescence that comes out from the interaction of protein clouds in a microgravity environment (Pavani et al. 2006). Comparison of these images with those obtained by performing the same experiment on earth gives information about how microgravity affects the clouds interaction. This is a fundamental step to study the chemical reaction of proteins in kinetic experiments performed in microgravity environment.

The protein clouds were generated by atomization of protein solutions using a SAW (Surface Acoustic Waves) device, specially built at CenPRA (Pavani *et. all.*) to perform the atomization function in a very efficient manner. The SAW device is a transductor that converts electricity into mechanic waves on the surface of a piezoelectric material. Although the chemical reaction is the core issue of the experiment and the construction of the SAW device is a very relevant point in the experimental set up, they are out of the scope of the present work. Here only the aspects concerning rapid manufacturing are taken into consideration as case study of applications of RM in scientific experiments.

Figure 2. Experimental set up. The video camera mounted on the top chamber built with SLS technology.

2.2 The artifacts built with selective laser sintering

The chamber was projected, built and the devices mounted on it at the Renato Archer Research Center (CenPRA) – a research unit of the Brazilian Ministry of Science and Technology. At that time, CenPRA counted only with SLS and 3DP rapid prototyping technologies, utilizing polyamide and plaster as building material respectively. The former was chosen because the polyamide prototypes present higher mechanical strength, dimensional and morphological characteristics. Additionally 3DP prototypes must be mechanically reinforced by infiltration of cyanocrilate that due to the fact it is a toxic resin would, probably, jeopardize a successful certification for using aboard the ISS.

The experimental apparatus (Fig. 2) consists essentially of two parts: a chamber for reaction control and a video camera for optical inspection. The artifacts, big and small, that make part of the chamber were built altogether in a SLS machine model Sinterstation 2000 (acquired from the old DTM Co., today the 3D System Co.) using virgin Duraform polyamide PA 2200 powder material supplied by EOS. This material was utilized because it was the only one available at that time. The machine parameters were: part bed temperature: 170-178 ^{o}C, laser power: 5,0 – 5,8 ^{o}C, layer thickness: 0.10mm, build high: 293,86 mm. 44 hours was spent by the machine to finish the build. None mechanical characterization of the material properties was performed and the decision to use it was based only on ISS certification tests.

In the present case the chamber consist of three concentric shells (Fig. 3 and Fig. 4) that are called inner shell, middle shell and outer shell. The inner and outer shells have octagon shape and the middle shell has circular shape. The inner shell is the main component of the chamber because in its interior takes place the interaction of the protein clouds.

On the exterior side of the shell are installed the fluidic system, leds and the SAW devices. On each convex corner of the octagon are fixed the syringes. On the external side of each wall there is a slot to fix the upper side of SAW devices (rectangular shape). The lower side is fixed with screws. Above the SAWs, the UV and white leds are installed at the same height. Holes trough the walls allow that the inspection and excitation light and also the protein clouds reach the

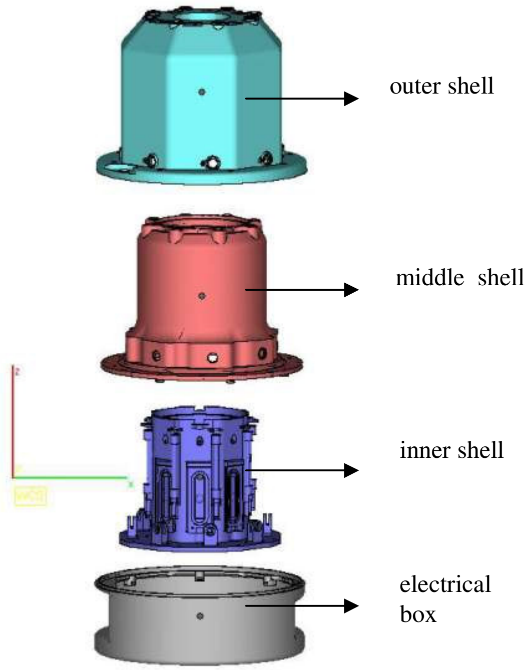

Figure 3. Schematic view of the three shells and the electrical devices support on the bottom

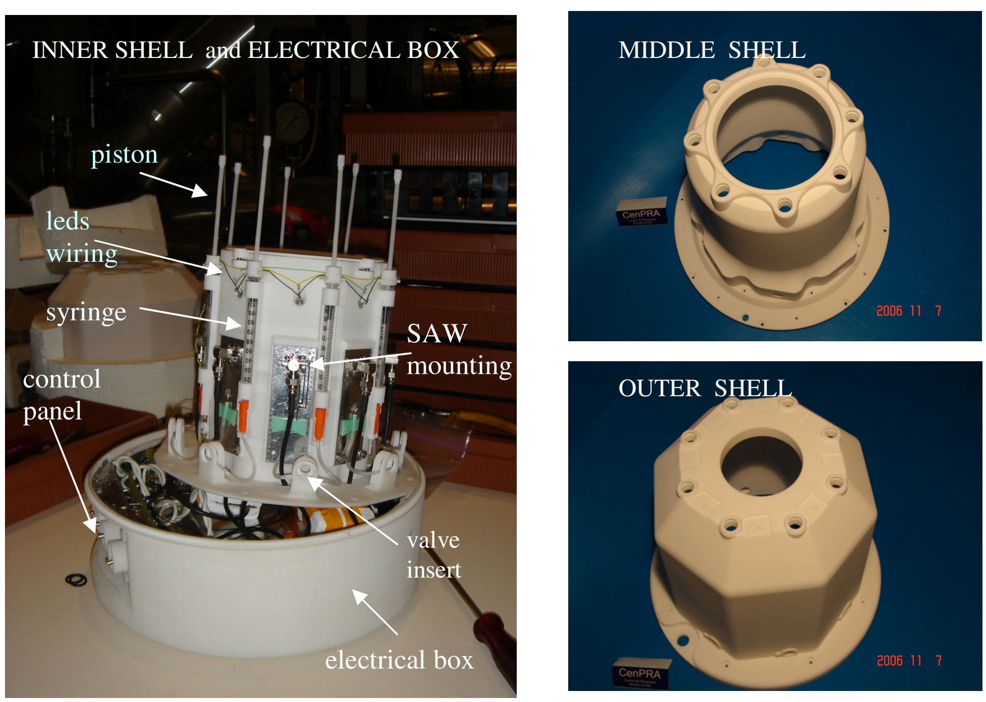

Figure 4. Left - Arrangement of the fluidic, electrical and mechanical components on the external side of inner shell and also electrical box (bottom). Right - middle and outer shell

interior of the inner shell. A hole on the top allows the images be captured by the video camera. The interior was black painted to favor the observation of the luminescent effect. The syringe is fixed by clamps. Clamps, access holes and SAW slots are all built integrated to the inner shell. The middle and the outer shell give additional structural support to the fluidic (valves and syringes) and optical (video camera) subsystems.

The three shells are fixed with screws to a support that accommodate the electrical arrangement such as batteries, PCB, wiring, switches. Spacers are use to fix one shell to each other. A support to fix the video camera to outer shell was also built. The small size devices include the syringe piston, pieces for fixation and valve components. The piston pieces and a small insert were machined to create screws. The screw structure transforms rotation movement of the piston into linear one. This arrangement allows better control on the amount of liquid dispensed.

2.3 Experiment Certification

The experiment was certified by the Brazilian Space Research Institute (INPE) and by the Russian Space Agency (ROSCOMOS). The tests consisted of simulation of the launching conditions such as the vibration caused by the rocket engine. Also electric, termovacuum, resistance temperature and toxicity tests were performed. ROSCOMOS gave the final approval to the experiment be sent to the ISS aboard the Soyus TMA-8 spacecraft.

2.4 Results and Discussion

The experiment was performed successfully (Fig. 5). The video images exhibit a static luminescence. This is the opposite behavior that was expected, i.e., a dynamic process where the clouds appear and disappear (Vasconcellos 2007). It should be noticed that it is a partial analysis of the video tape. The complete analysis and comparison with the experiment performed on earth to investigate the microgravity effect on the clouds interaction is still to be published.

The first good news about using rapid manufacturing to build the chamber is the fact that the material was mechanically and chemically stable to both the launching conditions and aboard the ISS. Besides the polymeric material is light and due to this fact the total weight of the experiment did not pass the weight limit of 3Kg that was required by ROSCOMOS. If the construction material was metal, as originally conceived, the chamber would be over weighted. In a further project we believe that a lighter and mechanically stable version could be built using hollow walls. Additionally the synterized polymer presents good density that allows screw being strongly attached. Another important advantage in utilizing RM instead the most conventional fabrication techniques is that the minimum amount of screws and none soldering was utilized. The clamps that kept the syringes in place were others important mechanical aspect considering the vibration undergone during the spacecraft launching.

Figure 5. Experiment being performed aboard the ISS.

The fact that the inner shell surface was porous worked favorably to the success of the experiment in two manners. Firstly in the fixation of the particles of black ink utilized to dark the interior side of the inner shell. Secondly by absorbing the molecules of the protein after the clouds had been formed. This molecule trap behavior is a contributing factor to prevent contamination of the ISS environment. Still concerning toxicity aspect it should be noticed that although the parts were build from powder material no powder was released. In other words the sinterization process was very efficient in the way that the amount of polyamide particles reached by the laser beam was very well attached to the each other while those out of the laser beam focus remained loose and easy to be removed in the powder removal step. It could be inferred that the build parameters allow an excellent temperature control. Also the use of the virgin powder could be an important fact in this result.

Finally another important point to consider was the short period of time that the microgravity RMSES was projected, built, tested and approved– three months.

2.5 Conclusion

The well succeeded experiment aboard the ISS has demonstrated that a complex system built in polyamide with SLS technology is mechanically and chemically stable to support all the severe tests associated to launch an experiment to be performed in a microgravity environment. From these results it is envisioned applications of the rapid manufacturing in building systems for a large variety of scientific experiments.

3. REFERENCE

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