New Design for Conserving Polymer Powder for the SIS Rapid Prototyping Process

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Abstract
Selective Inhibition of Sintering (SIS) is a Rapid Prototyping process that makes parts in a layer-based method by using polymer powders. Current SIS machines accomplish this layer-based method by heating a fixed area of polymer powder. The current process is an area of concern because the entire fixed area of each layer is cured, resulting in large amounts of polymer powder being wasted. This paper explains the design of an automated, mechanical system that will mask off areas of polymer powder with heat-resistant fingers, allowing for the adjustment of the heated area in order to cure minimal amounts of polymer powder at each layer. Test results of a prototype model showed significant reduction in polymer powder usage.

Keywords: Selective Inhibition of Sintering, SIS, Waste saving, Heater Design

1-Introduction

The Selective Inhibition Sintering (SIS) process is a newly patented additive fabrication (Rapid Prototyping) technology. The SIS process development research was initiated in 1999 at the University of Southern California. Recently research in this area have been furthered at other institutes, including this research that was conducted in the Department of Engineering and Technology at Texas State University-San Marcos.

The Selective Inhibition Sintering process, like many other RP processes, builds parts on a layer-by-layer fabrication basis. The SIS process works by joining powder particles through sintering in the part's body and by sintering inhibition at the part boundary. Advantages of the SIS Process include: Low cost, high speed, dimensional accuracy and surface quality, and the possibility of having a large build tank which will allow for fabrication of large parts and small to medium lot size production of multiple parts in a single run (in contrast, SLS cannot build large parts because at the far boarders the laser needs to deflect beyond the extent feasible for accurate part edge fabrication. Current the SIS process includes the following major steps (Figure 1) [1 and 2]:

0- The inhibitor tank is filled with the inhibitor liquid and the powder feed tank is filled with polymer powder, the inhibitor tank pressure and printer voltage are set, and the printer home is found. The printer nozzle is a miniature solenoid valve which requires back pressure. The voltage applied to the solenoid affects the response time and liquid pumping power.

1- The powder feed tank pushes the powder level upward in the amount of desired step(s). The build tank moves the powder level downward in the amount of desired step(s). The amount of lowering movement sets the layer thickness in the final part.

2- The cylindrical roller from the source tank spreads the powder over the build tank. The roller rotates clockwise and moves in the X direction.

3- An X-Y printer head moves the print nozzle over the desired layer profiles. The input file for the print pattern is the machine path file which is generated by the machine path generator system.

4- The heat source which is attached to the moving part of the machine (including the printhead and roller) moves in the X direction and its temperature and movement create a sintered layer with an unsintered pattern in the selected area of the powder bed. Steps 1-4 are repeated until the part is finished.

5- The model is removed from the sintered block and post processing including cleaning, and for certain materials adding wax to the fabricated part, completes the SIS process.

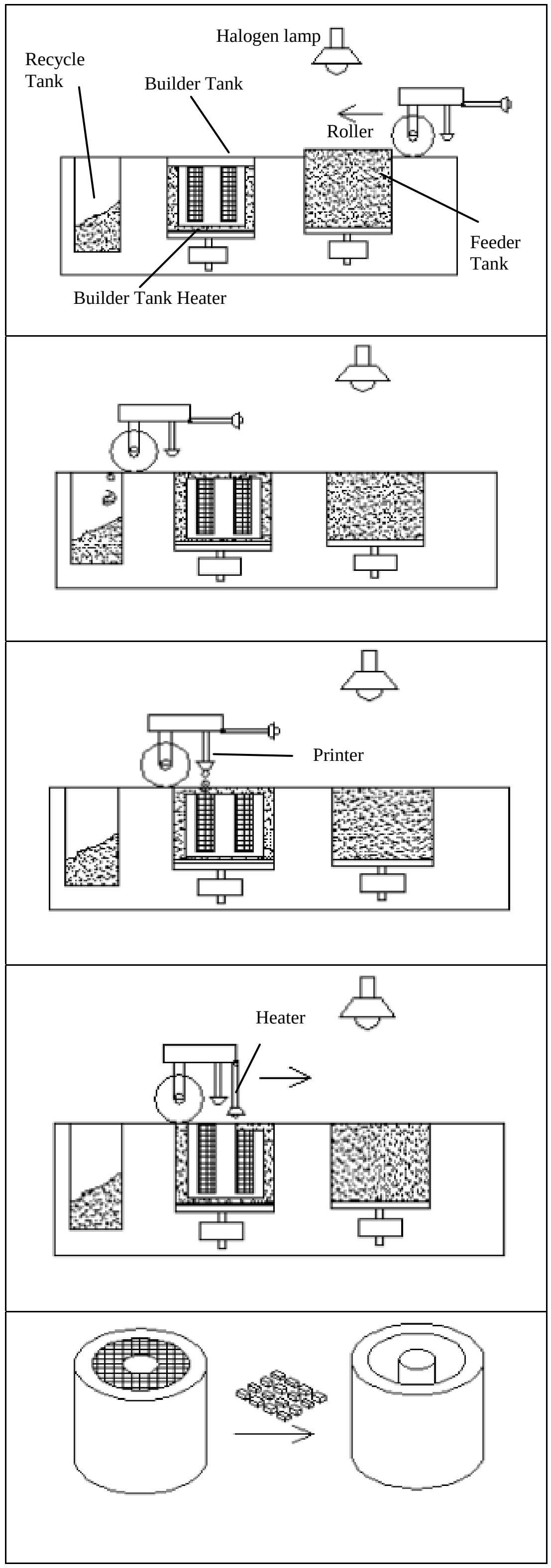


Figure 1. Selective Inhibition Sintering process steps

Figure 2 illustrates the SIS prototype machine operation. For the current machine a soluble salt (Potassium Iodide- KI) is printed as the inhibitor and Polystyrene is used as the polymer powder.

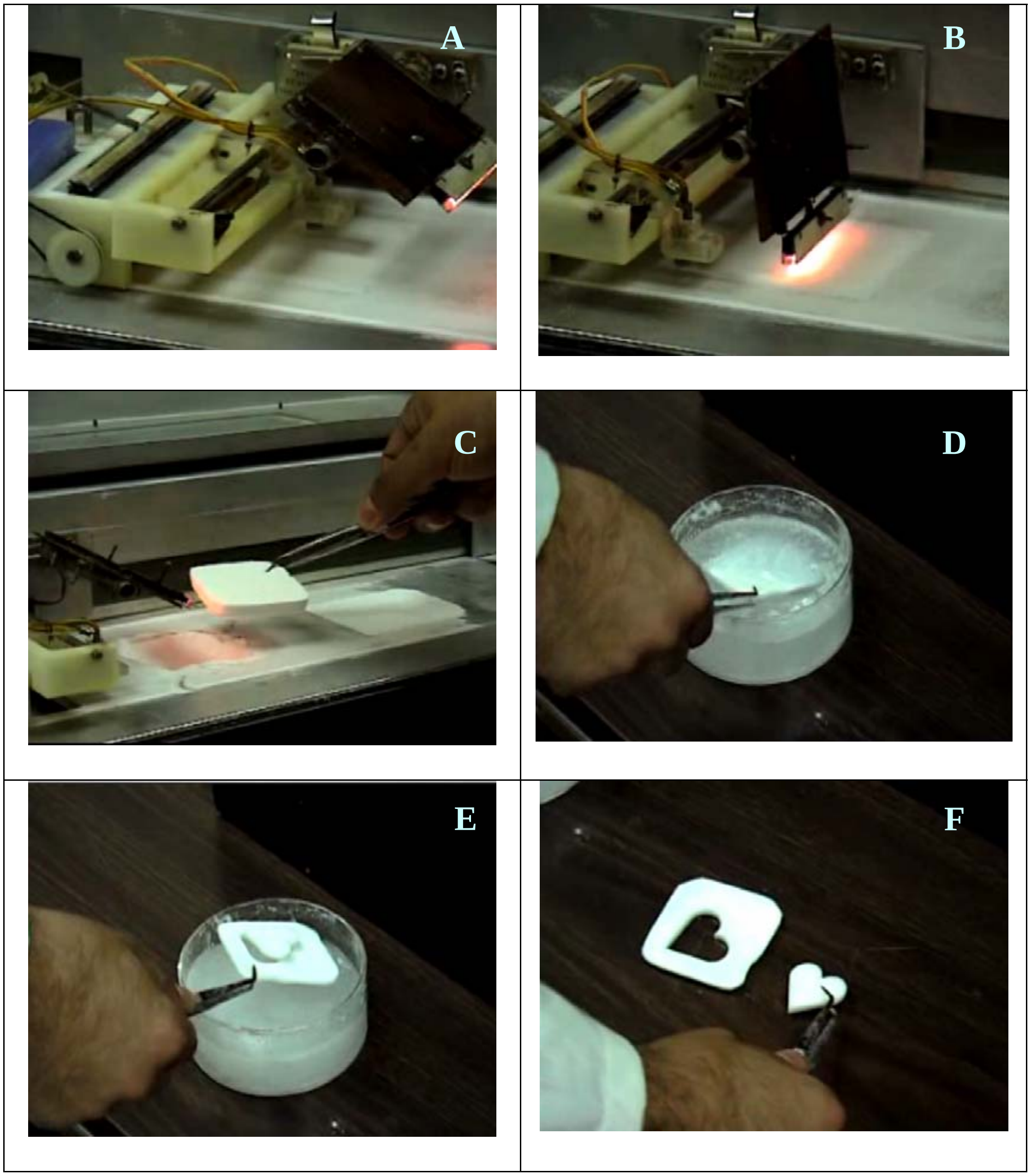


Figure 2- Steps for a sample part production using Potassium Iodide (KI) solution as the inhibitor: A) spreading the powder and printing the inhibitor, B) sintering (repeating steps A and B for multiple layers), C) removing the solid block from the build tank, D) Washing the block in a water-alcohol solution, E) dissolving KI salt into the water release part from surrounding material, and F) removing the part from the sintered block The next section highlights current process shortcomings which served in turn as the research motivation.

2- Results from previous research

An important issue for the SIS process was the necessity for uniform heat distribution of the entire surface of the build tank. Non-uniform heat distribution would produce parts with defective features such as bad attachment between layers and round and powdery corners while center of the layer was overheated. These defects would lower part properties such as strength, surface quality, and dimensional accuracy. This section explains a summary of the research previously conducted for optimum heater design [3].

2-1- Heater design by using radiation distribution simulation

Previous research showed, without losing considerable amount of accuracy, radiation is the main source of heat for the SIS process and conduction and convention heat transfer effects can be neglected. With this assumption best heater patterns were selected through illuminance concept. Illuminance is the amount of light falling on a particular surface and is shown with standard unit of Lux. Then AGI32 software [4] was applied to evaluate heat uniformity on polymer surface for different types of heater patterns.

2-2- Heater systems prototype and heat distribution

Once the preliminary patterns were determined, the heater prototype models for most promising patterns were built. Then, real heat distributions on these heaters were measured by using an infrared thermal image camera.

2-3- Powder surface heat distribution

To show the real heat distribution uniformity on the powder surface that includes radiation and convection effects; computer models were not sufficient. Therefore, a new experiment was designed and conducted. In this experiment, the temperatures of multiple points (with equal distance from each other) on a surface parallel to and with fixed distance from the downward heater were measured.

2-4- Physical part fabrication

After the thermal image evaluation, several sample parts were fabricated by using above heaters. Then, based on the quality of the produced parts (uniformity) and considering other important factors such as adjustability, heating time, weight, safety, and cost, a systematic scoring-based method was implemented. Figure 3 illustrates the summary of this experiment.

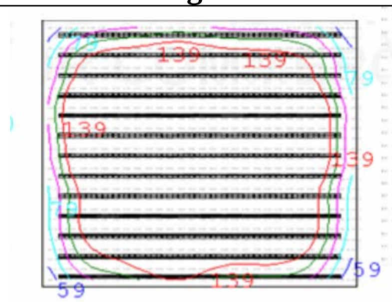
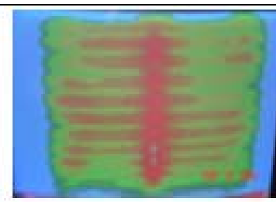
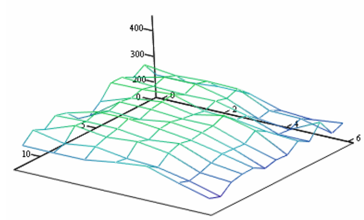
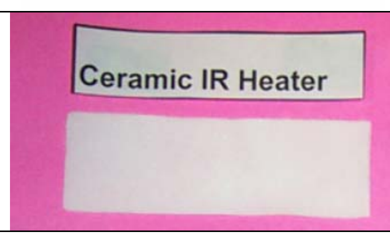
Step	Figure
1- Heat distribution simulation	
2- Thermal imaging	 
3- Point to point heat measurement	
4- Physical part fabrication	

Figure 3. Summary of the heater design for the SIS process

Results from this method suggest that commercial ceramic heater produces the most uniform sintered layers. However, long cool off time (several minutes) and weight are the drawbacks of this choice. Another promising alternative is heater made of nichrome wires with fiber composite board. This heater is very light, produces very uniform layers and cools very rapidly (a few seconds).

3- Research Motivation

The different heaters used in the current SIS process apply heat to a fixed area of the build tank surface [step B in Figure 2]. The end result of applying heat to the entire fixed area is that large amount of support polymer powder is being wasted. Figure 4 shows some parts made from the SIS Alpha Machine. Contrasting colors were used to indicate polymer powder waste. A great deal of polymer powder can be saved by selectively masking areas, which then would make the SIS process far less expensive. These motivations helped to evolve the research approach which is detailed in the next section.

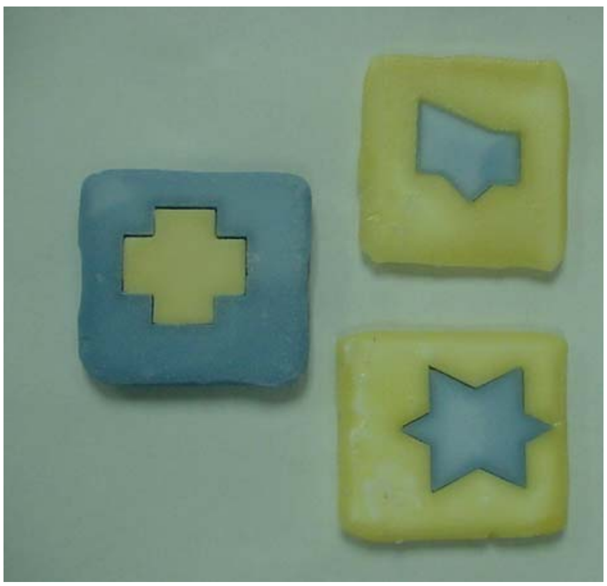


Figure 4. Current SIS process limitations: a) waste material

4- Research approach

In this research for any required design, multiple alternatives were primarily generated. Then, these alternatives were tested by means of different tools such as simulation, CAD model evaluation, and experiments. Therefore, number of alternatives to be physically developed was shrunk into a few alternatives. Also, in some instances results from tests helped to generate new alternatives (Figure 5).

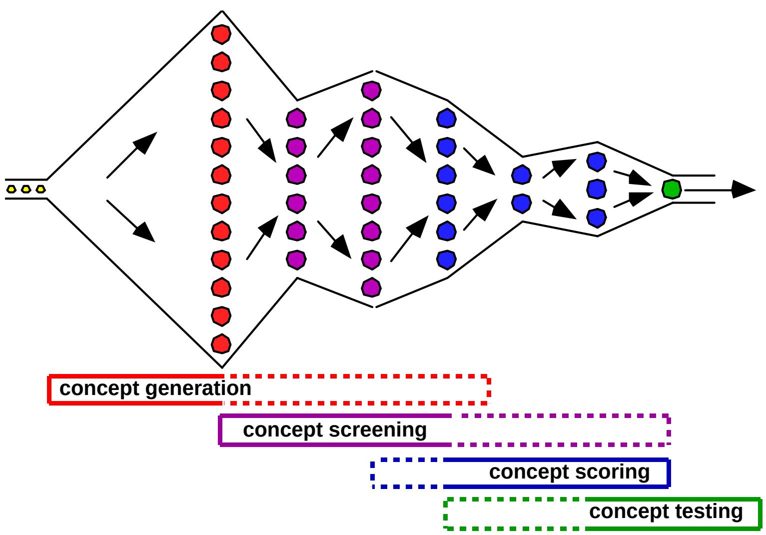
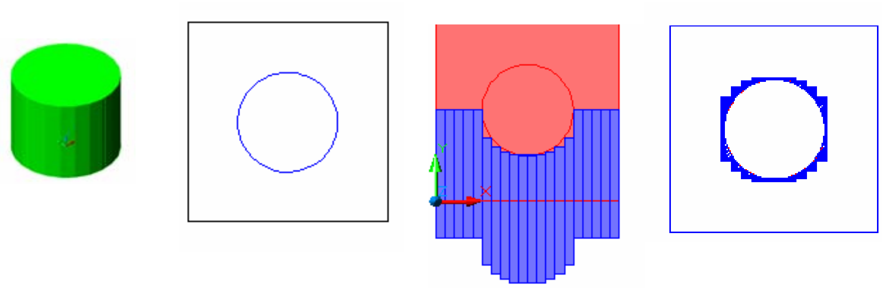


Figure 5. Alternatives generation and elimination

5- Mask system design and prototype

5-1- Mask system concept

In the current SIS machine, considerable amounts of polymer powder are being wasted because no mask system is being used. The role of this mask system is that they prevent heat from reaching the polymer powder surface in unwanted areas. For example, in Figure 6 to make a part (a), entire square area (b) is sintered while only small portion of it (circle area) is useful. Figure 6(c) illustrates mask system and dark area in (6d) shows the waste area.



(a) (b) (c) (d)

Figure 6. Moveable fingers mask system

5-2- Mask system alternatives

Different types of mask systems were proposed and the feasibility of each was studied (figure 7). Controlling air pressure based system (A) was hard because air pressure for every expandable mask should be controlled individually. Measuring tape system (B) was not practical to implement because one motor for every heat resistant roll was needed. For example in using 20 rolls, 20 motors should be installed on the machine. Heat absorber liquid spraying system (C) was a very promising idea; however finding appropriate liquid is challenging. Also, the whole idea of this waste saving effort is that the unsintered powder is to be used again for part production. Any additive to powder will change the quality of the fabricated parts. The powder should not include any other material but polymer powders. Potassium Iodide salt solution is currently being used for the SIS process as a heat mask. It has been effective for the part boundary. However, for external areas a lot of solution should be printed on top of the powder. After the heating process, separation of salt-polymer mixture is challenging and even after washing in water (figure 2.D) some salt particles will stay in the polymer and change powder property. A printable liquid that absorbs the heat and does not change powder quality has not been found yet. The finger mask system (D) was the most practical waste saving identified so far.

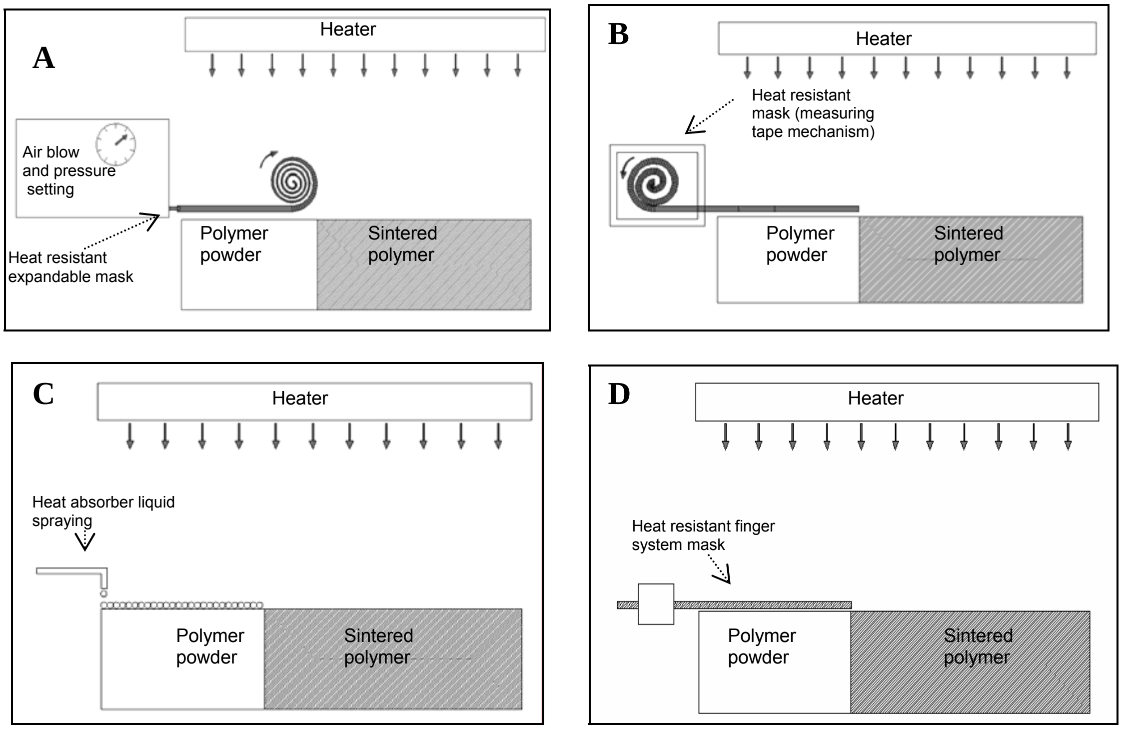


Figure 7. Proposed automated mask systems: A- Air pressure based mask expansion, B- Measuring tape-like expansion mask, C- Heat absorber liquid spraying system, and D- Finger system mask

5-3- Finger system design, prototype, and test

In the finger system which depends on the profile of each layer of the part, small heat resistant fingers move to such a position that the unwanted sintered powder (waste) is kept to a minimum. Figure 8 shows more details of the mechanical structure of this system. In this system two perpendicular rails give the flexibility to adjust the configurations for variety of profiles. MDF (medium density fiberboard) was selected as the material on which to mount the aluminum base because of its non-flammability property. In this system one motor in Y axis pushes a finger to the assigned position. Then, another motor moves this motor to a position such that the next finger can be moved. When a finger is required to be pulled back, a magnet system is activated for that finger which is made out of an electromagnetic base and MDF mask. Figure 9 illustrates mask system mechanism prototype. Finally, several parts were made by this system to test the performance of the mask system. As shown in figure 10, results were very successful in inhibiting from sintering in the selected areas.

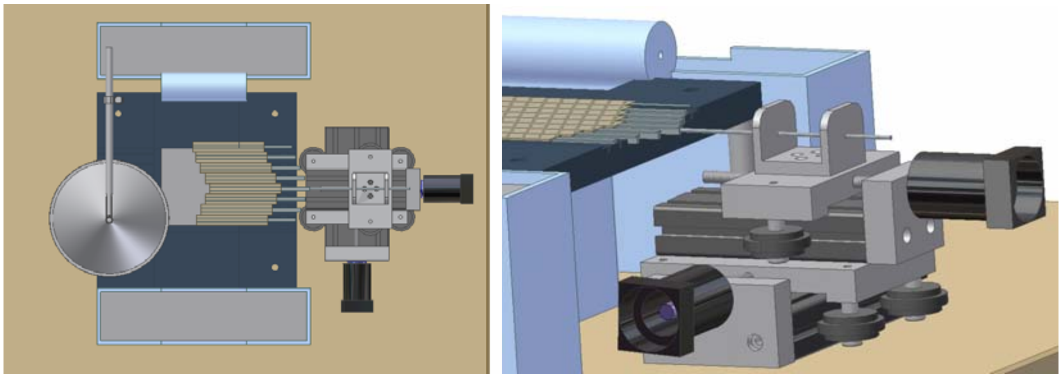


Figure 8. Finger mask system design. A similar mechanism mirror to this mask system will is placed on the other side of the machine.

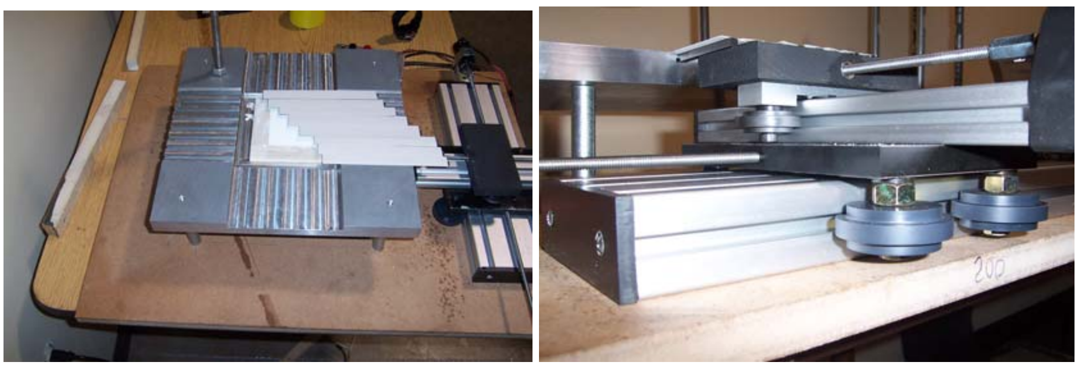


Figure 9. Finger mask system prototype

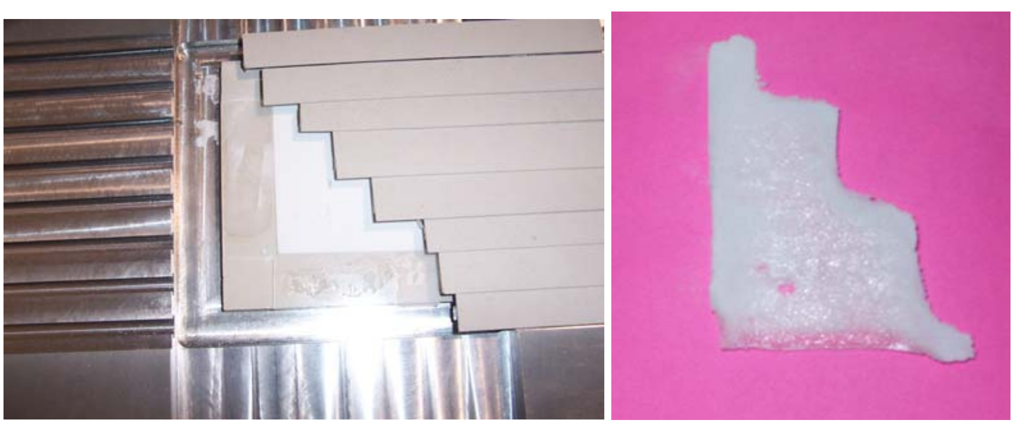


Figure 10. Adjustable fingers and inhibition of sintering in the selected areas

6- Summary

Material waste saving in the SIS rapid prototyping process was the major goal for this research. A finger based masking system was designed and prototyped. Test of the prototype shows very promising waste saving results. Tinier fingers will result in more precise waste saving, although complexity of the system will increase.

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