A HOMEMADE BINDER FOR GYPSUM BASED 3D PRINTER

I. A. Maia, M. F. Oliveira, J. V. L. Silva
Centro de Tecnologia da Informação Renato Archer - CTI
Rod. D. Pedro I (SP-65), Km 143,6 13069-901 Campinas – SP – Brazil
izaque.maia@cti.gov.br

ABSTRACT

Gypsum based 3D printer works by dispensing liquid binder via an ink jet head on layers of gypsum powder agglutinating the particles to form 3D parts. This work presents results relative to an attempt to substitute imported binder used in gypsum based 3D printer by a homemade one. A homemade binder was formulated based in two approaches as follows: (1) the homemade binder composition should be similar to the commercial one reveled in a patent but without the ink; (2) the migration of the homemade binder should present the same migration front in gypsum columns packed inside capillaries. A binder composition that presents the closest migration front compared with the commercial one was chosen to print physical testing samples. The testing samples printed with homemade binder and commercial binder show similar properties regarding dimensional accuracy, surface roughness, mechanical maximum tension and depowdering efficiency.

Key words: 3D printing, gypsum, binder, ink jet head

INTRODUCTION

For the last ten years the Renato Archer Information Technology Center – CTI, has been keeping a program called ProMED which supplies physical biomodels (Figure 1), built with 3D printing technologies, for supporting an increasingly number of complex orthopedic surgeries. The availability of these biomodels which are used in diagnosis, surgical planning and training has contributed significantly to diminish the suffering of severe injured people and giving them a better quality of life that otherwise could not be achieved.

Due to these benefits PROMED has been pursuing spread 3D printing technology in Brazil. Two major actions have been taken towards this objective. Firstly, developing and providing the InVesalius free software for medical 3D image reconstruction from x-ray tomography data. This software provides the digital model that will be printed with gypsum. Secondly, looking for ways to reduce the costs of building physical biomodels by the acquisition of a 3D Printing (3DP) machine to substitute the most expensive Selective Laser Sintering (SLS) 3D printer. In order to bring this costs further down CTI have been working in developing homemade 3DP consumables such as gypsum powder and binder. In the present work a homemade binder development is shown.

Figure 1. Skull biomodel built with gypsum based 3DP. On the computer screen is shown the corresponding digital biomodel.

Gypsum based 3D Printing is one of the various types of 3D printing technologies[1,2] in which gypsum powder particles, after being compacted in thin layers, is selectively bound by a liquid dispensed by nozzles such as those found in the ink jet print heads. By alternating successively the processes of layering and binding the powder, a three dimensional part is built. Post process includes depowdering followed by infiltration. Depowdering is the removal of the non binded powder using vacuum cleaner and brush followed by air jets whereupon the green part which is infiltrated with a resin to give mechanical strength. A major drawback of this technique is that the green part is quite fragile and consequently requires careful handling in all steps before infiltration. A major advantage is that whole process is carried out at room temperature.

This machine operates with a unique print head and utilizes the ZP® 102 additivated gypsum which is composed of the following dry compounds: calcium sulfate hydrate, vinyl polymer, carbohydrate, soda lime glass beads, calcium sulfate dihydrate, fatty acid ester and salts (Z Corporation 2004). The binder is water based and is dispensed by a HP thermal print head (hpc4800a model). The machine automatically replaces the ink by the binder. The chemical reaction involved in the powder binding promotes a crystallization process. This process is intensified until a large amount of crystals is formed and interlock with one to another to form a dense solid part.

As the ZPrinter® 310 utilizes the same ink print head of the commercial 2D printers sold everywhere it was inferred that the composition of the binder should present the same set of compounds except the dye and its associated additives. A first proposal for a homemade binder composition should then include, at least, water and a surfactant agent. The water plays the role of the both crystallization agent and the solvent vinyl polymer that is an additive of commercial gypsum. The surfactant has multiple functions. It helps the penetration of the binder in the print medium, avoids drop deflection from the print head nozzle plate, controls the size of the drop and finally it works as an emulsification agent. Highly viscous emulsion works as a barrier which confines the binder in the limits of the zone where the binder drop collides with the powder layer[3].

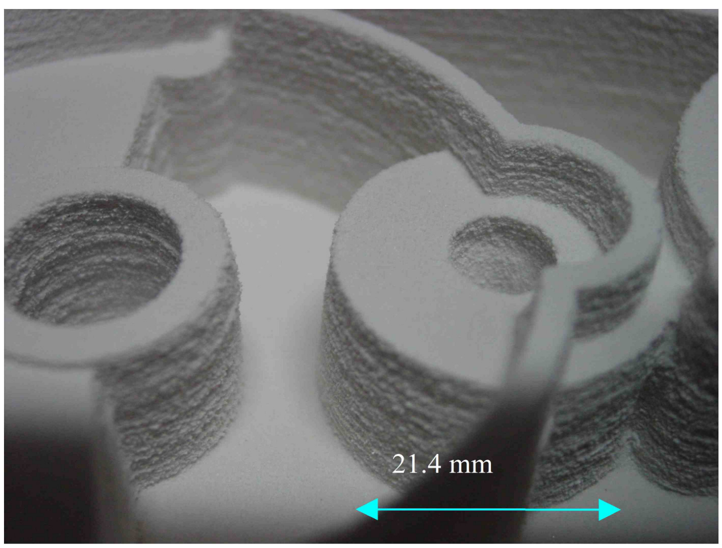

Figure 2. Surface roughness of the part built with water only as a binder

The motivation for pursuing a homemade binder composition for gypsum based 3DP was a promising result obtained by printing a complex part utilizing distilled water only. This part, shown in figure 2, presented dimensional and mechanical characteristics closed to the part which was built using the commercial binder. Moreover the part was handled and undergone the depowdering step without any damage. However the morphology of the walls parallel to the z axis exhibited severe surface roughness which was clearly observable by naked eye. The objective of this work is to formulate a homemade binder which gives parts having better dimensional, mechanical and morphological characteristics than those built with distilled water and as closest a possible to those built with commercial binder.

MATERIALS AND METHODS

Testing binder solutions

The chemicals used to prepare the testing binder solutions was based on those revealed in the patent regarding to the ink of thermal ink jet heads[4]. Based on that a first approach was taken into consideration for choosing which ink chemicals would be used to formulate the testing binder solutions. This approach states that once the commercial binder is colorless the dye and their associated additives could be removed without jeopardizing the binding property.

Table 1. Weight concentration of compounds in water solutions to be tested as homemade binder

Solutions	Surfactant	ethanol	Isopropyl alcohol
	%	%	%
1	0,0999	0	0
2	0,1499	0	0
3	0,2997	0	0
4	0,4250	0	0
5	0,4246	9,9800	0
6	0,4256	9,9950	4,9975
7	0,3002	9,9967	5,2316

A second approach is related to the relative amount of the essential ink chemicals, namely, water, anionic surfactant, monoalcohol (ethanol) and polyalcohol (isopropyl alcohol), in the testing binder solutions. Although it is not clear the role played by both alcohols on the ink properties they were used in the water solution besides the surfactant. It is a rather empirical approach based on the consideration that different composition solutions will migrate differently in gypsum powder columns. A measurement value called Migration Height value (H) was then established. The best testing binder solution should be that whose H value was closest to that achieved by the commercial binder. The compositions of test solution are given in Table 1. As a starting point for the formulation the amount of surfactant in samples 1 and 2 was chosen based on the weight percentage required to reach the CMC (Critical Micellar Concentration).

The experimental set up is presented in Figure 3. To prepare the gypsum powder column the powder was introduced into a plastic tube (4.4 mm diameter) which had one of their sides covered with a permeable membrane while the other side remained opened to the air. In order to have the same packing degree the tubes filled with gypsum were allowed to drop three times in the vertical position from the same height position. Then the membrane side of each tube was immersed in a corresponding solution. All tubes were left in contact to the solutions for a same period of time (1 minute) and H was immediately measured after the tubes were removed from the solutions.

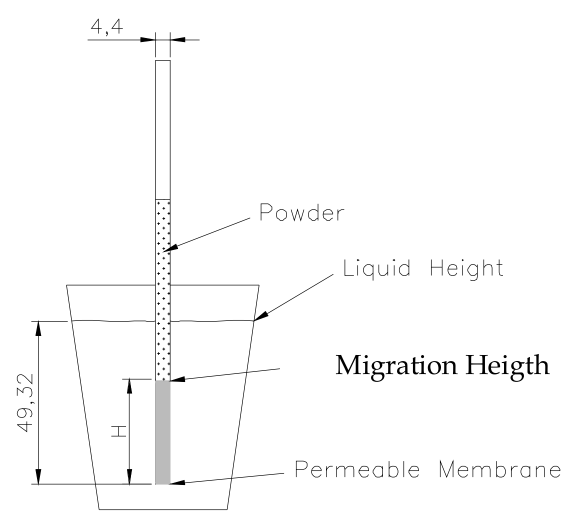

Figure 3. Schematic drawing of the experimental setup to determine the Migration Height (H) of solutions (dimensions in millimeters).

A set of testing parts were printed using both the commercial binder and the chosen test binding solution. It was utilized a ZPrinter® 310 machine and ZP®102 powder (Z Corporation®) which is based on gypsum as the main component. The testing parts are defined in Table 2 and Figure 4 according to the type of characterization employed.

Table 2. Types of testing parts related to the functional characterization

Reference	Shape	Functional Characterization
S1	Dog bone (ASTM638)	Maximum mechanical tension
S2 with three different aspect ratio – a, b, c	Block with different diameters of trespassing holes	Depowdering efficiency
S3	dumbbell	Dimensional
S4	cylinder	Porosity / cyanocrylate infiltration

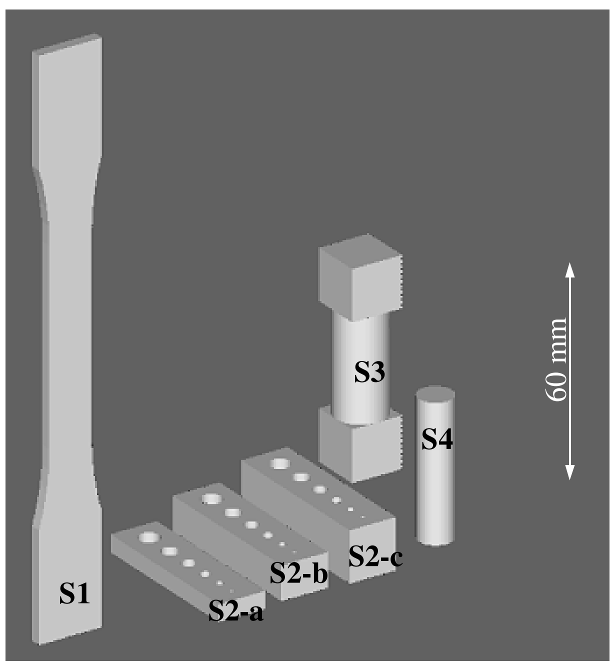

Figure 4. Schematic drawing of the testing parts built with homemade and commercial binder and applied as follows: S1-tensile test; S2a,b,c –depowdering efficiency; S3 – dimensional characterization, S4- cyanoacrylate infiltration.

The printing parameters were also the same, i.e., layer thickness (0.1 mm) and value saturation (100%). The samples were built in two different directions: parallel and perpendicular to the Z axis in order to evaluate if the binders follows the same behavior regarding the build orientation.

After depowdering, the testing parts were not infiltrated except the cylinders (S4) that are used to porosity/infiltration evaluation.

Evaluation of the surface roughness of the testing parts was made by naked eye. Dimensional measurements were made using a caliper ruler (0.001 mm precision). The mechanical characteristics were qualitatively evaluated by handling the parts after removal from the part bed (build region of the printer) and through the depowdering process.

The quantitative mechanical characterization consisted of raising the stress strain curves (EMIC DL 300 machine with 100 N transducer) from which it was obtained the maximum tension (MPa). Also the mechanical characterization was evaluated indirectly by measuring the cyanoacrylate infiltration in the cylinders. The infiltration front depends on the material porosity which is a critical factor that determines mechanical strength. The infiltration was made by immersing the cylinders in cyanoacrylate for 10 seconds. To expose the infiltration front the cylinders were firstly cut parallelly to the circular sections. Afterwards the non infiltrated material presented in the cylinders core was thoroughly removed utilizing water jets. To give a good contrast the empty cylinders cores was filled with liquid wax and then pictures was taken with a digital camera (Sony F828, 8 megapixels resolution).

The depowdering efficiency was evaluated by attempts to remove the non binder powder from the holes having different aspect ratio (S2,a,b,c) with air jets. Aspect ratio refers to the height/diameter ratio.

RESULTS AND DISCUSSION

Characterization of the test binder solution

The H values for different test bind solutions are given in Figure 5. The chosen solution was that whose H value was the closest to that reached by the commercial binder was chosen as the homemade binder and used then in the printing tests.

Solution 6 was chosen as the homemade binder because it fulfills the two following conditions: (1) it contained all basic compounds of the ink utilized in ink jet print head and (2) it presented the H value closest to that of the commercial binder (Figure 5). It should be noticed that the both conditions are arbitrary and they were taken as two empirical approaches to formulate a homemade binder. The migration approach was mostly based on the feeling that the migration of the binder on the machine part bed should be similar to those of the columns. Moreover there is some question that should be answered for a better understanding of the migration mechanism, for instance the severe drop of H value (solution 5) by adding alcohol to the solution 4 which contains only water and surfactant. However a detailed investigation of the physical chemistry phenomenon is beyond the scope of the present work and due to this fact it should be considered as an exploratory work.

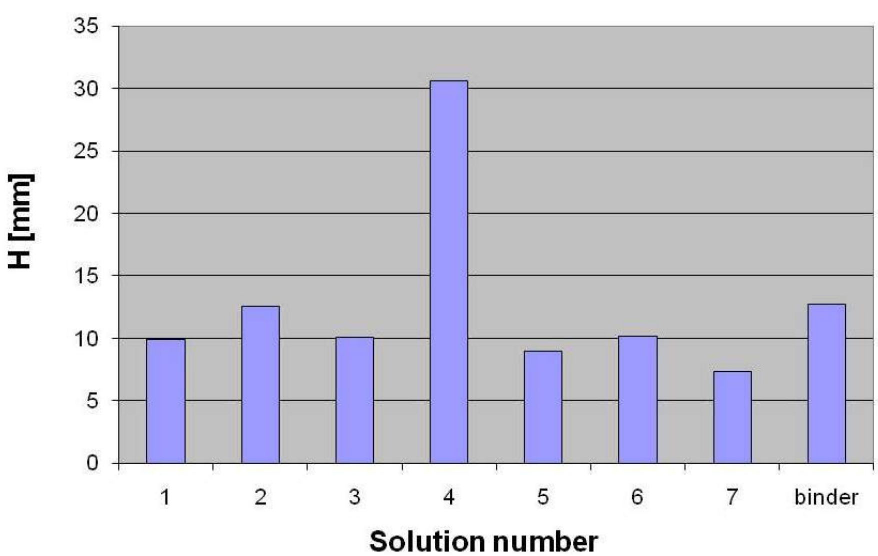

Figure 5. Migration front (H) of water solution of surfactants and alcohol. The numbers given in the X axis refers to the solutions shown in Table 1.

Parts Characterization

In despite of the exploratory character of the testing binder experiments, the approaches adopted have allowed obtaining satisfactory results concerning roughness surface, mechanical strength, dimensional characterization and depowdering efficiency as explained as follows.

Surface roughness: The parts built with the chosen homemade binder presented much less surface roughness than that found in parts printed with water. Better still it presented similar surface roughness compared to that found in parts printed with commercial binder.

Mechanical strength: The maximum tension obtained from the stress-strain curves (Figure 6) showed that the maximum tension of the test parts built with the chosen homemade and commercial binders are similar except for sample D whose the maximum tension of the homemade binder is considerably higher than that of the commercial binder For both binders it was confirmed the expected behavior in which the parts built perpendicularly to the z axis (samples A, B, C) are stronger than those built parallelly to the z axis (samples 2 and 3).

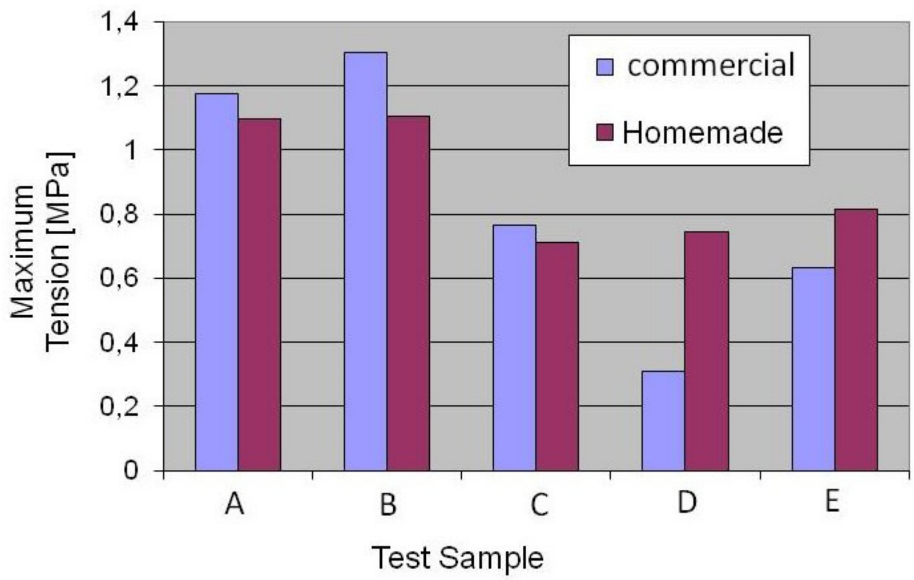

Figure 6. Maximum strength exhibited by parts built with commercial and homemade binders. Samples A and B were built perpendicularly to the Z axis and samples C, D parallelly to the Z axis.

Among the three samples built parallelly to the Z axis, the maximum tension of the sample built with homemade binder is greater than those built with commercial binder. This is corroborated by the infiltration experiments. Cyanoacrilate infiltration front of the cylinder built parallelly to the z axis with homemade binder is narrower, therefore less porous, than the infiltration front related to commercial binder parts (Figure 7). This could be indicating that the homemade binder migrates more efficiently towards the layers interface. This is another phenomenon that should be investigated in a further work. Regarding the cylinders built perpendicularly to the z axis (Figure 8) the opposite occurs. Those built with commercial binder are stronger because they present lower infiltration, therefore are less porous, than those built with commercial binder.

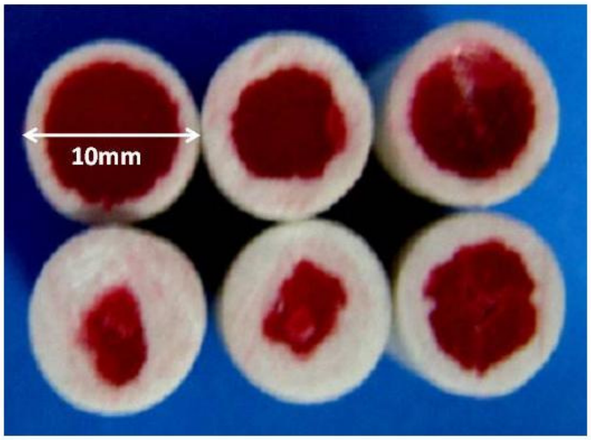

Figure 7. Cyanoacrylate infiltration in cylinder samples built parallelly to the Z axis: The white contour shows the infiltration front in the cylinders built with homemade (top) and commercial (bottom) binder. The black core is wax that replaced the non binded powder that was removed.

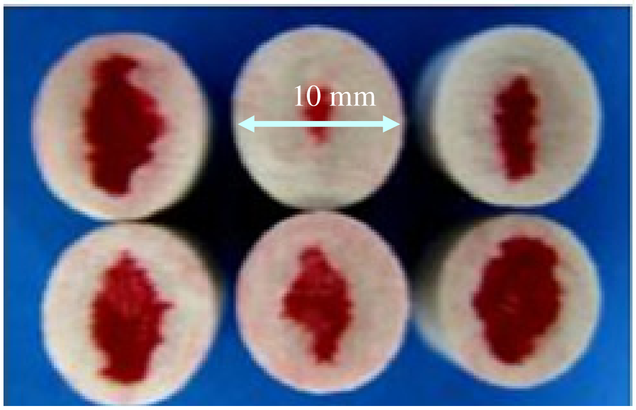

Figure 8. Cyanocrilate infiltration in cylinders samples built perpendicularly to the Z axis: The white contour shows the infiltration front in the cylinders built with homemade (top) and commercial (bottom) binder. The black core is wax that replaced the non binded powder that was removed

Dimensional characterization: The percentage difference between the parts built with homemade and commercial binder in both positions - parallel and perpendicular to the z axis – is in the 0,2%-2.0% range. Although these differences could be considered acceptable for many applications they show that improvements can still be done in the homemade binder.

Depowdering efficiency: None noticeable difference was observed regarding the depowdering efficiency. This means that the migration of the homemade binder during the printing process was similar to the homemade binder.

CONCLUSION AND FURTHER WORK

It should be keep in mind that this is an exploratory work based mainly on the assumption that the best formulation of the homemade binder would present the same migration value (H) of the commercial binder. This assumption was reasonably confirmed by these results presented here. The chosen homemade binder is a water solution having the following weight percentage: surfactant: 0,4256 %, ethanol: 9,9950 % and isopropyl alcohol: 4,9975 %. The orientation of the part parallel or perpendicular relating the Z axe of part build should be taken into account for mechanical properties evaluation.

A further work will include detailed studies about the migration of the binder into the powder and formulation of a homemade powder. The achievements of both quality homemade gypsum and homemade powder will lead to considerable decreasing of the costs of biomodels bringing as result considerable contribution for the Brazilian Heath System – SUS.

AKNOWLEGMENTS

The authors wish to thank the Division of Qualification and Analysis of Electronic Products (DAPE) of CenPRA for the tensile tests.

REFERENCES

[1] PHAM, D.T.; DIMOV S. S. **Rapid Manufacturing** London: Springer-Verlag 1980.

[2] COOPER, K. G. **Rapid Prototyping Technology: Selection and Application**. New York: Basel, Marcel Dekker, 2001.

[3] WILLIAM, C. R.; CIMA, M.J; PRYCE, L.; WENDY, E., D. C.; MONKHOUSE, D; KUMAR, S.; YOO J. **Methods and materials for controlling migration of binder in a powder**, US Patent number 20040062814, 2004.

[4] LAWP, H. P. **Specific dye set for thermal ink-jet printing**, US Patent number 5534051, 1996.