KAUNAS UNIVERSITY OF TECHNOLOGY
MECHANICAL ENGINEERING AND DESIGN FACULTY

Ignas Tepcovas

PRINTABILITY OF DENTAL CERAMIC MATERIALS USING A PIEZOELECTRIC NOZZLE

Master's Degree Final Project

Supervisor
Assoc. prof. dr. Marius Rimašauskas

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Industrial Engineering and Management (code 621H77003)

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KAUNAS, 2016

KAUNAS UNIVERSITY OF TECHNOLOGY

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(Title of study programme, code)

"Printability of dental ceramic materials using a piezoelectric nozzle"

DECLARATION OF ACADEMIC INTEGRITY

____ June 2016
Kaunas

I confirm that the final project of mine, **Ignas Tepcovas**, on the subject "Printability of dental ceramic materials using a piezoelectric nozzle" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarized from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by law) have been paid to anyone for any contribution to this thesis.

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KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Approved:

Head of Production Engineering Department

Assoc. prof. dr. Kazimieras Juzėnas

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT

Study program: Industrial Engineering and Management

The final project of Master's studies aimed to gain the master's qualification degree is a research or applied type project. 30 credits are assigned for its completion and defense. The final project of a student must demonstrate the more profound and extensive knowledge acquired in the main studies as well as the gained skills enabling the student to outline and solve an actual problem when in possession of limited and/or contradictory information, to independently conduct scientific or applied analysis and to interpret data properly. By completing and defending the final project of Master's studies, a student must demonstrate creativity, ability to apply fundamental knowledge, understanding of social and commercial environments(s), Legal Acts and financial limitations, to demonstrate information search skills as well as ability to carry out analysis requiring advanced qualification(s), to use quantitative research methods, to apply relevant software, to use common information processing techniques and correct language and to demonstrate the ability of formulating proper conclusions.

1. Title of the project

Printability of dental ceramic materials using a piezoelectric nozzle.

Approved by the Dean Order No.V25-11-7, 3 May 2016

2. Aim of the project

To investigate the possibilities of 3D printing in dentistry and design a nozzle capable spraying dental ceramic material in a desirable fashion.

3. Structure of the project

Research part: dental ceramic usage in manufacturing dental structures; opportunities in using CAD/CAM and additive manufacturing technologies; main parts of a 3D printer and operating principles of the printing head; piezoelectric effect in additive manufacturing; operating principles of piezoelectric materials. **Project part:** spraying of dental ceramic materials using a piezoelectric nozzle; measurements of dental ceramic material particle size and solubility; suggestions for improving the spraying system of the nozzle. **Economic part:** market analysis of dental ceramics and dental crowns. **Graphic part:** Schemes, figures, graphs, tables, drawings.

4. Requirements and conditions

Material in relevant topics is analysed and concluded. Tests are done using scientific methods, have clear objectives, performed in a logical order, relevant results or conclusions. Suggestions for improvements has to be reasoned and supported by an implementation plan. Economic analysis has to refer to relevant statistics or calculations. Graphic part has to be understandable, logically presented.

5. This task assignment is an integral part of the final project.

6. Project submission deadline: …………………………………..

Given to the student ____

Task Assignment received ________________________ ____________________

(Name, Surname of the student) (Signature, date)

Supervisor ________________________ ____________________

(Name, Surname of the supervisor) (Signature, date)

Tepcovas, Ignas. Printability of Dental Ceramic Materials Using a Piezoelectric Nozzle. Master’s thesis / supervisor assoc. prof. dr. Marius Rimašauskas. The Faculty of Mechanical Engineering and Design, Kaunas University of Technology.

Study area and field: Production and Manufacturing Engineering, Technological Sciences.

Keywords: additive manufacturing, dental ceramics, piezoelectric effect, spraying nozzle, 3D printing.

Kaunas, 2016. 42 p.

SUMMARY

The project focuses on the possibilities of using additive manufacturing technologies in production of dental structures. Using such technology would benefit society by decreasing the time and resources required to produce the desirable result.

Production of a dental crown is being done by a skilled technician. It takes a lot of time to reach a result, which in turn increases the overall price of the crown. Since the material used for dentistry is widely available, it is only necessary to combine it with a technology that would produce an object out of it. 3D printing could be one of such technologies to date.

Parts of this research work include usage of dentistry ceramics, its behavior in various conditions, introduction of possible solutions for occurring problems, presentation of a design of a spraying nozzle for ceramic printing.

Tepcovas, Ignas. Odontologijoje naudojamų keraminių medžiagų spausdinimas naudojant pjezoelektrinį purkštuką. Magistro baigiamasis projektas / vadovas doc. dr. Marius Rimašauskas. Kauno technologijos universitetas, Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir sritis: Gamybos inžinerija, Technologijos mokslai.

Reikšminiai žodžiai: adityvi gamyba, dantų keramika, pjezoelektrinis efektas, purkštukas, 3D spausdinimas.

Kaunas, 2016. 42 p.

SANTRAUKA

Projekte didžiausias dėmesys skiriamas adityvios gamybos technologijų panaudojimui keraminių dantų karūnėlių gamyboje. Tokios technologijos naudojimas būtų naudingas visuomenei, nes sumažėtų sąnaudos reikalingos pasiekti norimą rezultatą.

Paprastai danties karūnėlės gamybą atlieka technikas. Tokiu atveju užtrunkama daug laiko, o tai kelia karūnėlės kainą. Pasitelkus esamas technologijas turėti būti galimybė automatizuoti ir pagreitinti gamybos procesą. Šiuo atveju 3D spausdinimas galėtų būti tokia technologija.

Šis tiriamąjį darbą sudaro dantų karūnėlių keramikos nagrinėjimas, darbo metu susidariusių problemų sprendimo pasiūlymai, keramikai skirto purkštuko modelio pristatymas.

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INTRODUCTION

Ceramic use in dentistry is comparatively a recent innovation. On the other hand problems occurring on teeth are well known. These problems have a huge impact on appearance and health of an individual. This is why possibilities to deal with such problems have been introduced: cavities are filled, wear is restored and a missing tooth is replaced with an implant [1].

This work is mainly focused on the possibilities to use dental ceramic with additive manufacturing technologies. Dental ceramics are materials designed for producing dental prosthetics. These prosthetics are used to replace missing or damaged dental structures.

On the other hand dental ceramics are comparatively weak when functional forces are applied. This is a great disadvantage for ceramics as restorative materials. When compared to metals and other dental materials, ceramics exhibit low level of toughness. In this case further development is required and these improvements in materials has enabled their use in partial restorations and structures over dental implants [2].

All in all growth in the ceramics field produces better quality for ceramic dental structures. Properties, such as fracture toughness and strength, are being improved and the end result is becoming more favorable for the public.

Furthermore a demand for efficient production of dental crowns is on the rise. Since the technology is already here, it is necessary to combine it for further usage in the field. In this case a combination of ceramic material with 3D printing possibilities may provide with the necessary results.

Main aim – to investigate the possibilities of using additive manufacturing technologies in dentistry and design a nozzle capable of spraying dental ceramic material in a desirable fashion.

Tasks:

1. Review dental ceramic usage with additive manufacturing technologies.
2. Analyze requirements for printing with a ceramic material.
3. Perform tests using the acquired ceramic materials.
4. Present results and offer solutions.
5. Investigate the economic benefits.

The research project is divided into 4 main segments:

- research on dental ceramics and its usage with additive manufacturing technologies;
- testing of the acquired dental ceramics;
- analysis of occurring problems and solution suggestions;
- economic overview.

Master thesis consists of: 42 pages, 4 appendices, 34 figures and 5 tables.

1. OVERVIEW OF ACHIEVEMENTS IN ADDITIVE MANUFACTURING METHODS AND USAGE OF DENTISTRY CERAMICS

1.1. Research of ceramics use in dentistry

In this chapter ceramics and their properties are analyzed. Several articles were explored in order to have a better understanding on what ceramics are used for dentistry and why is it the better choice than other materials.

Improvements are being made in materials and their processing techniques regarding dental ceramics. Such progress influences the development of CAD/CAM technology, where ceramic materials can be used. CAD/CAM outperforms conventional material processing techniques, so an increase in variety of materials used is observable. This leads to an increase in favorable properties of dental materials – higher density, lower porosity, increase in microstructural uniformity, decrease in residual stresses [2].

1.1.1. Strength and fracture toughness

Structural ceramics may be described with the following two coherent properties – strength and fracture toughness [2].

Ceramic materials are mainly failing, because of brittle fracture – no deformation takes place before fracture occurs. Combining it with other surface flaws and the result is low strength of the ceramic structure. However improvements in the field, such as reduction in particle size and smooth particle distribution, resulted in increase of strength of the ceramic material.

Fracture toughness is the ability of a material to resist crack growth. But in this case a simple flexural strength test is not enough. Such test shows how much load can a structure take, but in this case it is more important how many smaller loads the structure will take before cracking (which is equivalent to chewing). Fracture toughness for zirconia ceramics is between 8 and 10 MPa m1/2, which is about 2 times better than aluminum materials. In this case zirconia would be a better choice for dentistry as it requires a longer period and more energy to crack.

1.1.2. Strengthening of ceramics

In case ceramics do not meet the necessary strength requirements, they may be toughened. 3 types of strengthening possibilities are categorized further: crack tip interactions, crack tip shielding, crack bridging [2].

When a microcrack occurs it is important to stop it from developing further. This is done by interaction of particles under the first layer. These particles redirect the crack into a different plane. In such case the crack is no longer influenced by the stresses that originally caused the cavity to appear.

When high stresses occur in the region around a crack, the particles of material act in such a way, that these stresses are reduced. This is achieved by changes in the location of particles with respect to the stresses that occur onto the structure (shielding).

When a crack occurs, the second layer of particles act as a bonding agent. This is achieved through the structure of the material particles. Crack bridging is important for reducing the possibility of a crack to open.

1.1.3. CAD/CAM with dental ceramics

Zirconia is the leading ceramic in toughness of the material. This is achieved by the material-specific transformation toughening mechanism. This is the reason why zirconia is the best selection for manufacturing dental structures. On the other hand dental crowns are complex structures, so manufacturing is not ordinary [3].

Nevertheless opportunities in manufacturing with dental ceramics have increased since CAD/CAM (Computer Aided Design / Computer Aided Manufacturing) technologies have been introduced in the field. The technology is not yet fulfilling all tasks, but substantial progress is still being made.

Two main manufacturing methods available with the use of CAD/CAM technology:

1) manufacturing of dental structures by machining fully sintered blocks of ceramic material;
2) manufacturing of dental structures by machining partly sintered block of ceramic material and then fully sintering the structure.

Subtractive milling is the process used for both of these methods. In any case there are limitations of why these methods might be unpopular for manufacturing:

1) high quantity of material waste is present after manufacturing;
2) ceramic pre-form may be required for complex shapes in order to obtain a desirable result, which in turn have to be produced and handled;
3) complex process, which does not guarantee a dependability of the structure.

Another option for production of dental crowns is additive manufacturing. Such techniques have potential of producing components with elaborate shape and structure. In addition generative manufacturing is a fast and accurate way of production, while the waste of material is minimized [3].

With the help of additive manufacturing it is possible to use the building material to produce small units of the component and then integrate these units together. These are several most commonly used methods for production of ceramic components: stereolithography, robocasting, selective laser sintering, 3 dimensional printing, laminated object manufacturing and direct inkjet printing. Further research on several of these methods are presented in the next chapter.

1.2. Analysis of additive manufacturing methods

This chapter is dedicated to get deeper understanding about various generative manufacturing methods. Different approaches are used for these methods, where materials and their utilization affects work time, product accuracy and final price.

Table 1.1 shows a comparison of different methods for producing dental structures.

Table 1.1 Comparison of different production methods

Manual	**PROs**	Materials available	Comparatively low cost	Easy to achieve favorable result
	CONs	Start from scratch every time	Time wasting process	Modifications are “random”
Mould casting	**PROs**	Materials available	Very low cost if mould is present	Result is close to perfect every time
	CONs	Very costly and time consuming to produce a mould	Mould is for one structure usage	-
Subtractive manufacturing	**PROs**	Materials available	Time saving	Use of CAD/CAM technologies
	CONs	Lots of wasted material	-	-
Additive manufacturing	**PROs**	Use of CAD/CAM technologies	Time saving	Several processes at the same time
	CONs	Materials not available	Technology not adjusted	-

It is clear that conventional production methods are not sufficient enough and there is plenty of room for improvements. Further focus on additive manufacturing methods is required in order to assess the production possibilities.

1.2.1. Stereolithography

Stereolithography (SLA) is a generative manufacturing method, where a photo sensitive resin is being cured by a concentrated UV light. After a layer hardens, it is then immersed down into the resin and another layer is cured on top of it. After the last layer is cured, the product is lifted form the resin.

In 1986 Chuck W. Hull registered stereolithography in his US Patent 4,575,330, by the name of "Apparatus for production of three-dimensional objects by stereolithography" [4].

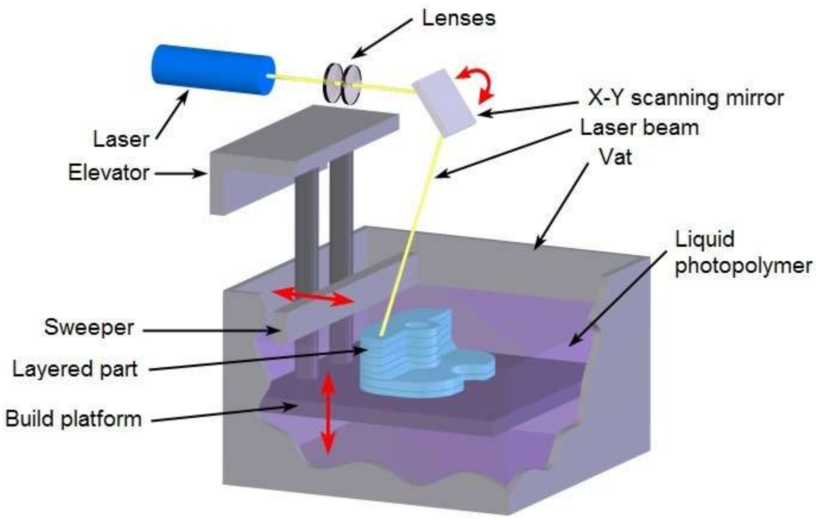

Figure 1.1 Stereolithography [5]

Stereolithography is mostly beneficial for its speed. Production time depends on complexity of the part, but parts of high dimensions (up to 2 meters) can be produced in several hours. Products of stereolithography are durable and may be used for further processing.

On the other hand, parts produced by stereolithography are expensive, which in turn suggests that the technology is economically unviable. Other additive manufacturing methods may be more promising.

1.2.2. Robocasting

Another generative manufacturing method is robocasting. During robocasting a product is formed by extruding a filament of material from a nozzle. Each layer is built on top of the last one and the product is being created. The material leaves the nozzle in a liquid state, but dries fast by itself to maintain the required geometry, so there is no requirement for curing.

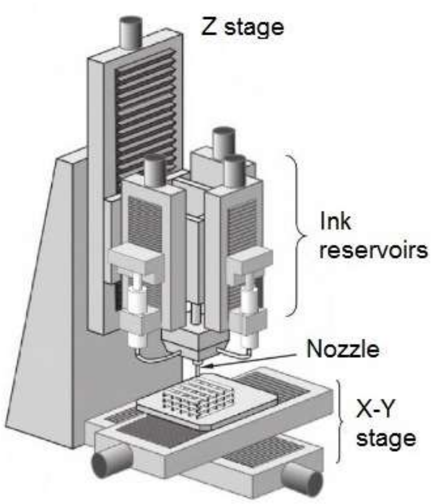

Figure 1.2 Robocasting [6]

Robocasting results in complex geometries of high accuracy. In addition it is possible to manufacture products from materials, which are biologically compatible with human tissue. Such research leads to production of dental crowns.

1.2.3. Selective laser sintering

Selective laser sintering (SLS) is a method, where a laser joins material particles together in order to produce a desired structure. This is done by providing a 3D model to the system, so that the laser is targeted at the required positions.

This method was patented as "Method and apparatus for producing parts by selective sintering" by Carl R. Deckard in 1989 in his US Patent 4,863,538 [7].

A layer of material is solidified by the laser beam and the part is lowered into the powder bed. After that a new layer is solidified on top of it. Since the part is submerged in the building material at all times, there is no need for a support material, so time and resources are saved.

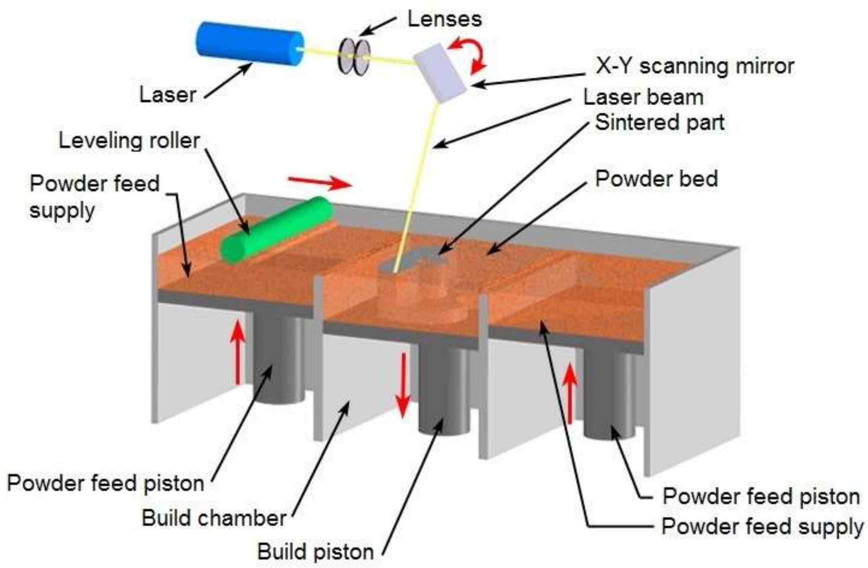

Figure 1.3 Selective laser sintering [8]

A large variety of materials can be used for selective laser sintering. These include: polymers, polystyrene, various metals and alloys. In addition it is possible to produce several parts simultaneously in the same powder bed. This leads to efficient use of material and lower production time.

1.2.4. 3 dimensional printing

3 dimensional (3D) printing is an additive manufacturing method, where an object is produced by laying layers of material on top of the last one with respect to a predefined CAD model. 3D printing usually requires a support material to keep the model material in place and assist with the actual print.

I have selected Objet30 3D printer for further analysis. Next chapter contains a further overview of the printer itself, its software and routine maintenance possibilities.

1.3. Overview of Objet30 3D printer

This chapter is required to get deeper understanding about the selected 3D printer. The printer itself and guide for it were both examined and the results were concluded. This was done to have a thorough knowledge of how such machinery works and future prospects of the project.

1.3.1. Objet30

The Objet30 is a 3 dimensional desktop printer, which is as accurate and flexible as an expensive additive manufacturing machine. It is mainly designed for prototyping models and small consumer products [9].

Figure 1.4 Objet30 3D printer

Objet30 has a roomy tray size with 8.388 dm^3 (appendix No. 1) of build space. Therefore it is possible to print several samples in one batch. This would allow saving time if several samples are being printed at the same print.

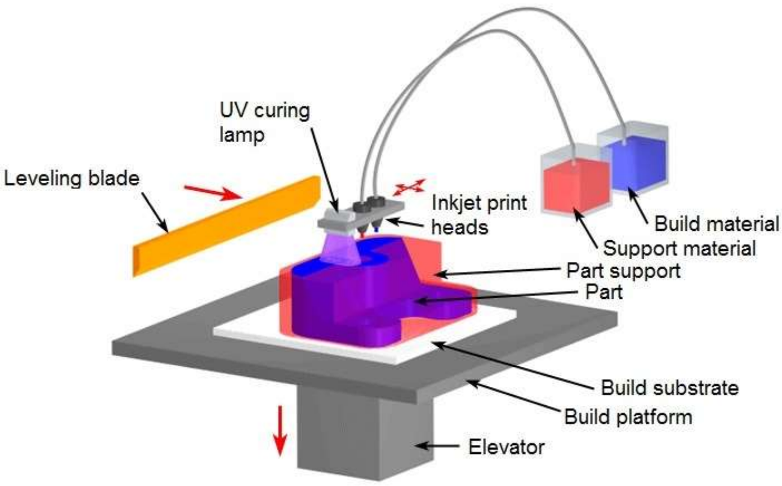

Figure 1.5 Scheme for 3D printing

Objet30 has typical parts required for printing 3 dimensional models. These parts include inkjet heads (printing head), elevator, leveling blade (roller) and UV lamp.

In order for a 3D printer to work it has to have a movable printing head. The printing head of Objet30 is moving through 2 axes: X and Y. This movement provides with printing of 2 dimensional sketches.

Both printing material and support material are being heated until they reach the desirable temperature. Printing material is shot down through the inkjet head and onto the model. In the meantime printing head is in constant motion. Layers of the model are being created and the model is being built.

The other inkjet print head is for the support material. Printing in 3 dimensions could be easy for simple designs, but in order to print a difficult design it has to overcome difficulties. Since the model is printed in layers, some layers might not be printed on top of the last layer, but rather has to be printed on air, if there is no layer under it.

Since printing requires an actual layer to print on, a support material has to be used while printing the product. All the spaces, holes and sockets are printed as the product but it is done with the support material rather than the model material.

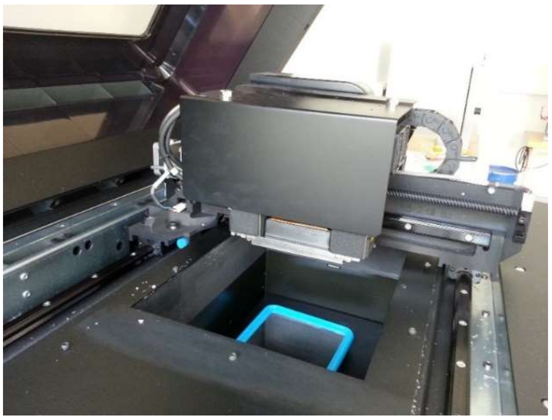

Figure 1.6 Printing head

After a layer of the model is printed, the elevator goes down 28 microns, so the next layer can be printed on top of the last one. Addition of this method allows for printing in the Z axis. Now the model becomes a 3 dimensional one.

Another part of the printing head is a roller. After both materials are on the surface and a layer is finished, surface of the layer is not smooth. The roller rolls on the surface of the model to make it smooth. After this is done the next layer is sprayed on a clean surface so the accuracy is kept high.

1.3.2. Printing software

Objet30 uses a dedicated software program in order to function properly. Figure 1.7 shows the main display of the software. It includes various status indicators, which assist with operating the printer.

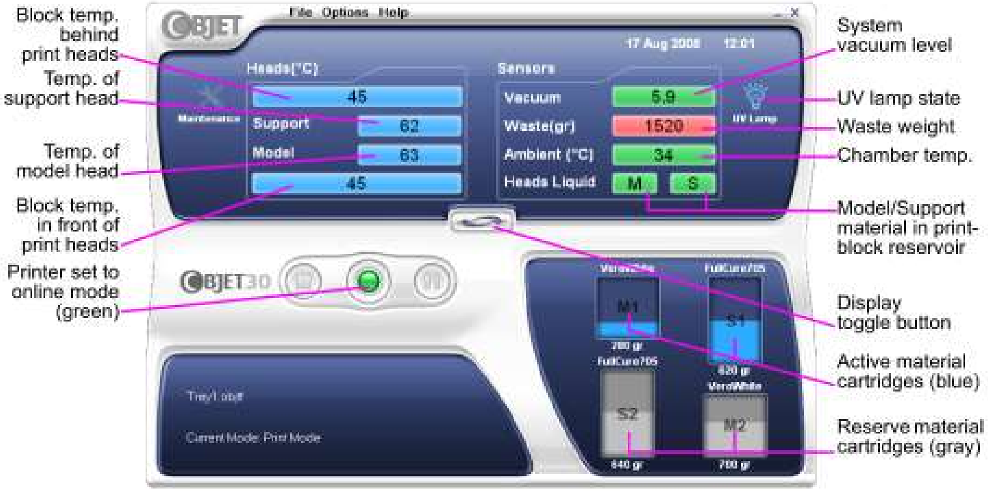

Figure 1.7 Printing software [10]

Indicators provide real time information for the operator. This information include [10]:

- temperatures of the printing heads, support and model materials, printing chamber;
- amounts of support and model material left in active and reserve cartridges, waste material;
- overall status of the printer.

1.3.3. Printer maintenance

In order for the printer to be operating properly, it needs regular maintenance. Following parts are checked to ensure serious problems will not occur during printing:

- printing heads;
- build tray and surrounding area;
- roller and waste collector;
- material cartridges;
- activated carbon filter.

In order to successfully service the printer, several simple tools and materials are required. These include:

- scrappers of different sizes;
- small mirror;
- isopropyl alcohol 99% (IPA) or ethanol (ethyl alcohol);
- cleaning cloth;
- disposable gloves.

Figure 1.8 Maintenance tools

Basic maintenance is quite simple and done before every printing. This keeps the machine capable of printing models in high precision. In addition machine wear is slower with regular maintenance. Persistent supervision ensures that the printer will do its job for a sustained period.

1.4. Printing and dosing principles

In this chapter possibilities of a spraying nozzle is being analyzed. Parts in this chapter cover basics of a typical inkjet printer, its parts and technologies used, piezoelectric effect and its usage possibilities, piezoelectric nozzle, its operating principles and testing, further development.

1.4.1. Printing machine

In order to print desired objects, a printer is required. It is important to analyze how a typical inkjet printer works. One of the methods used in a printer is piezoelectric. This method uses piezo crystals. A reservoir of ink has an outlet, which is two sided. One side has a piezo crystal and the other side is the nozzle for printing [11].

When the crystal receives an electric charge, it causes a vibration in the crystal. This vibration reduces the volume in the outlet and forces ink out of the nozzle. When the crystal vibrates inward, it forces a tiny amount of ink out of the nozzle – a droplet of ink is sprayed out [12].

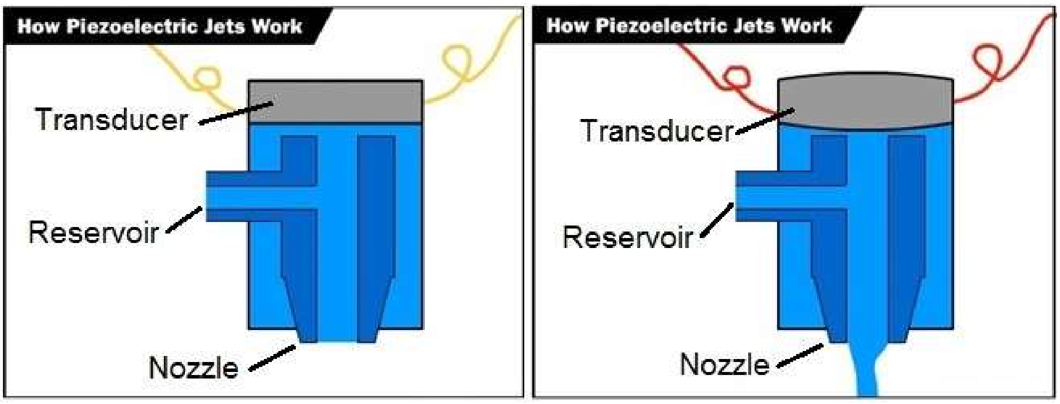

Figure 1.9 Piezoelectric jet without and with electric current present [12]

After that the crystal vibrates out and pulls in more ink from the reservoir to replace the sprayed ink. This is repeated quickly and indefinitely until the desired outcome is obtained [13].

1.4.2. Piezoelectric effect

In our case piezoelectricity is most promising in achieving the desired result. Piezoelectric effect as an ability of various materials to generate an electric charge when mechanical stress is applied. In other words, when a piezoelectric material is under tension or compression, an electric charge is generated [14]. Piezoelectric effect is further explained in figure 1.10.

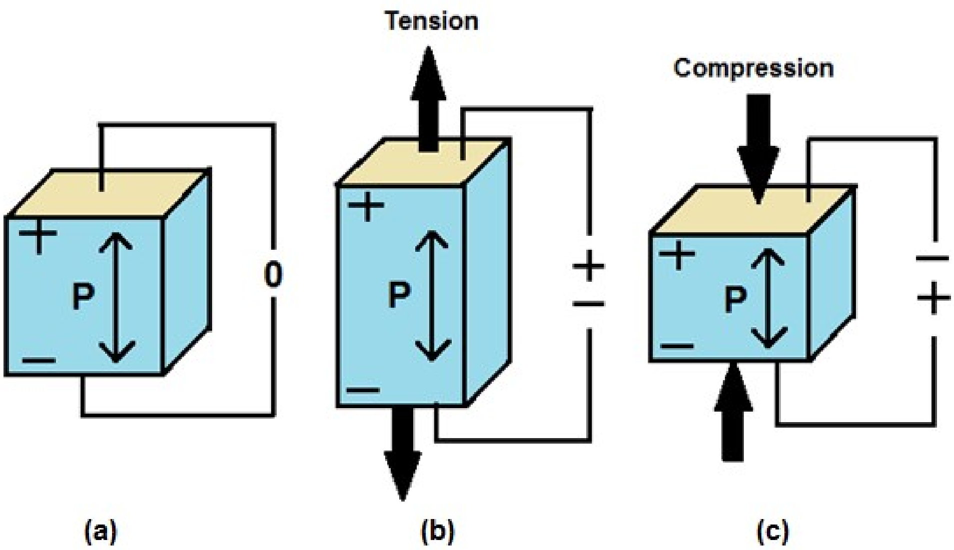

Figure 1.10 Piezoelectric effect [15]

a) No external force is applied – electrical charge is not being generated.
b) Tension is applied – electrical charge is generated.
c) Compression is applied – electrical charge is generated with a direction opposite to tension.

Most favorable characteristic of the piezoelectric effect is that it is reversible. In this case a material showing the direct piezoelectric effect (generation of electrical charge when stress is applied) also displays the converse piezoelectric effect. This means that stress is being generated when an electric field is applied to the material [15].

When mechanical stress is applied onto the piezoelectric material, the positive and negative charge centers are shifted in between. This leads to generation of external electrical field. If the process is being reversed, the electrical field puts stress onto the piezoelectric material (tension or compression).

Piezoelements may vibrate in various configurations. Different forms of vibrations have its own range of frequency. Figure 1.12 shows vibration activity of piezoelements with respect to their range of frequency [16].

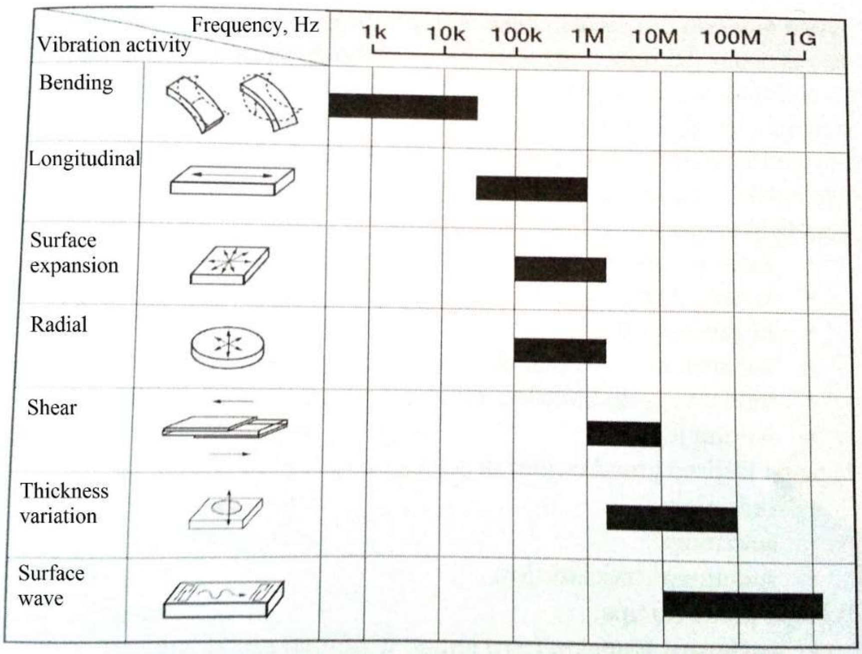

Figure 1.12 Vibration forms and natural frequencies of piezoelements [16]

It is clear that some activities (longitudinal vibration) has lower frequency than others (thickness variation). Natural frequencies from 0 to 1M to more than 1G Hz for different activities.

1.4.3. Travelling wave dosing principles

Travelling wave type deformations are caused by friction forces on the surface of solid bodies. These forces interact with the material particles and cause them to move in the direction of the traveling wave [17].

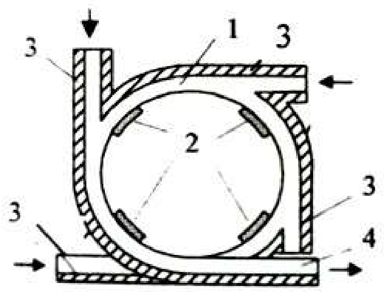

Figure 1.13 Spiral doser with several intake channels [17]:

1 – spiral tube, 2 – piezoceramic vibrators, 3 – intake channels, 4 – outtake channel

Figure 1.13 is a scheme of a doser, where the tube (1) – a spiral rectangle channel, with piezo-chamber vibrators (2) on the inside of the tube. These vibrators form the travelling wave deformation on the channel surface of the tube. Such dosing scheme allows mixing several different liquids coming from different channels at once (3) and one channel (4) to dose the mix out.

Here is an example of horizontal doser, which uses the same travelling wave principle. Figure 1.14 shows the scheme for such microdoser:

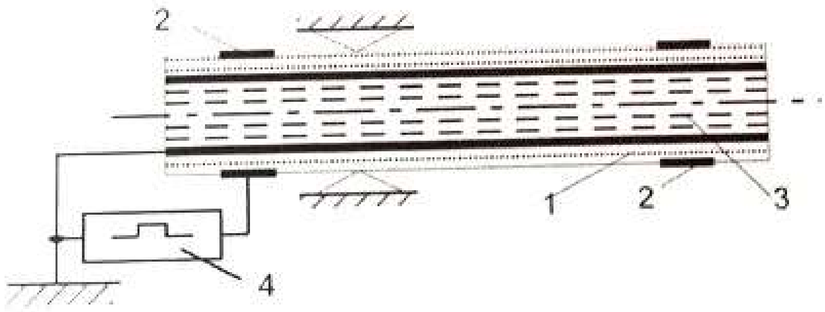

Figure 1.14 Microdoser scheme [17]:
1 – piezoceramic tube, 2 – electrodes, 3 – material flow, 4 – alternating current

The piezoceramic tube (1) has electrodes (2) attached. Alternating current (4) is provided to the electrodes and thus to the tube. Walls of the tube start to vibrate – travelling wave deformation occur. Friction force between walls of the tube and material inside it (3) lead to its movement in the direction of the travelling wave. It is possible to control the parameters of the travelling wave and speed and amount of material flow by changing various parameters of the electrical signal – amplitude, time, frequency.

Another example of a doser is designed for the feed of fine liquid droplets. Scheme of such construction is presented in figure 1.15.

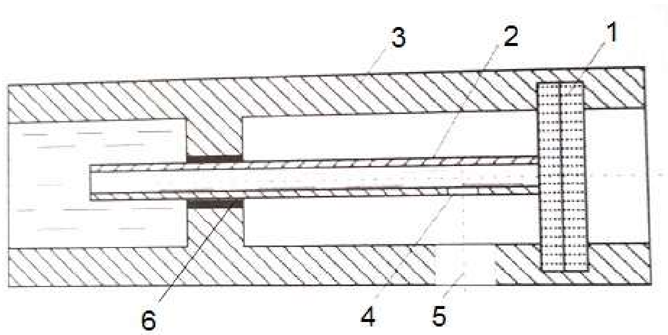

Figure 1.15 Fine particle doser [17]:
1 – piezoceramic disc, 2 – capillary tube, 3 – doser frame, 4 – micro hole, 5 – spraying gap, 6 – sliding connection

A piezoceramic disc (1) generates longitudinal vibrations in the in the capillary tube (2). The tube is inserted horizontally to the doser frame (3). One side of the tube is fixed in the center of the element, while other side is inserted into a sliding connection (6), which is immersed into the dosing material. In addition there is a micro hole (4) in the tube, which is in the same axes as the micro hole (5) of the frame. Piezoceramic element stimulates the vibrations of the capillary tube, which spray the material inside, while the reversible linear movement spray the droplets out from the gap (5).

1.4.4. Standing wave dosing principles

Operating principles of dosers, without moving structural elements, are based on the formation of acoustic standing waves inside a closed frame filled with a liquid [17].

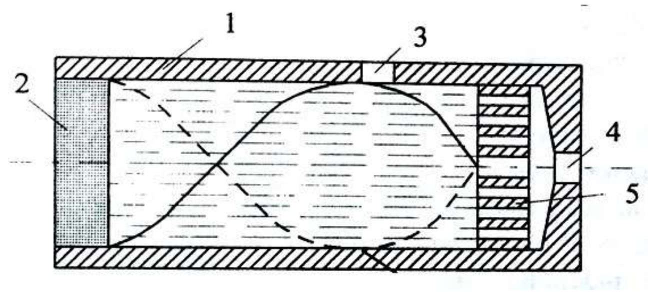

Figure 1.16 Standing wave principle doser [17]:
1 – cylindrical frame, 2 – piezoceramic disc, 3 – intake hole, 4 – dosing hole, 5 – capillary screen

Figure 1.16 shows the structure of standing wave principle. In this scheme the doser is formed of a hollow cylindrical frame (1), which has a piezoceramic disc (2) on one side and a liquid dosing hole (4) on the other. There is a capillary screen (5) in front of the dosing hole and the intake hole (3) is located perpendicularly to the screen.

In order to ensure that the conditions allow occurrence of standing waves, it is very important to evaluate parameters of the dosing liquid and the whole vibratory system.

2. EXAMINATION OF DENTAL CERAMICS ACQUIRED AND TESTING

2.1. Examination of the materials

In this chapter material used in dentistry is being analyzed. Parts in this chapter include material available, its properties and applications. Figure 2.1 shows materials used for testing.

Figure 2.1 Ceramic and modelling materials

Two ceramic materials and one modelling material alongside water were used for tests. Testing include examination of materials and their usage with piezoelectric nozzle.

2.1.1. IPS d.SIGN

IPS d.SIGN Dentin is an apatite glass-ceramic material. It is most appreciated for how lifelike it looks, which is very favorable. In addition apatite is a component of natural teeth. It supports optical properties of light – translucency, brightness, light scattering [18].

Material properties of IPS d.SIGN:

- Flexural strength (ISO 9693) – 80 ± 25 N/mm^2
- Coefficient of thermal expansion – 12.0 ± 0.5 10^{-6} K^{-1}m/m (2 firing cycles)
  12.6 ± 0.5 10^{-6} K^{-1}m/m (4 firing cycles)
- Transformation temperature – 510 ± 10 °C (2 firing cycles)

VITA modelling liquid is used additionally in order for the ceramic material to remain smooth during layering without any loss of stability. In addition it ensures maximum process reliability due to lower shrinkage during firing [19].

It is important to use a modelling liquid in order to correctly control the moisture content of the ceramic. If the material is too dry – it will tear. If it is too moist – it will run and it will not be possible to layer the material. VITA facilitates a smooth consistency and ensures moist processing over a long period as well as effective stability.

2.1.2. Cerabien ZR

Cerabien ZR (CZR) is a porcelain specifically developed for the making of ceramic crowns in use with zirconia frameworks. Crowns made from CZR are very usable due to its extremely high flexural strength. The combination of CZR and zirconia will result in boosted esthetics. In addition such combination is fitted with maximum strength for a top-notch restoration [20].

Definitive features of CZR [21]:

- Emulation of shading generated by real teeth;
- Ability to easily combine with zirconia frameworks;
- Excellent characteristics of material storage and usability;
- Results in a remarkable stability;
- Highly resistant to fractures and chipping.

Overbuild by approximately 10% is necessary in order to allow shrinkage. After the crown is built, it is required to bake it in 930-940 °C. Baked porcelain should have a definite sheen. If in any case the porcelain does not obtain a definitive sheen, it is then required raise the temperature in order to get the desired surface texture.

2.2. Spraying of the ceramic material

2.2.1. Model of the piezoelectric nozzle

Since piezoelectric material deforms with applied electricity, we can use this property to our advantage. By applying electricity with high frequency we are able to apply vibration from piezoelectric material to its surroundings. In this case we need to design a nozzle for the material to sprinkle. Figure below shows parts required for a nozzle to perform:

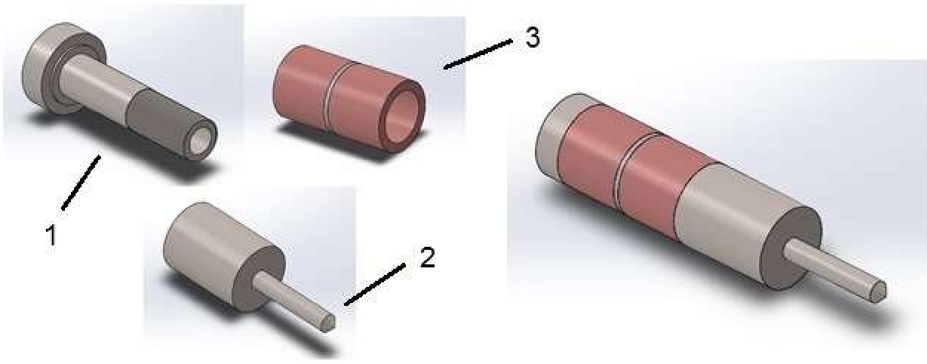

Figure 2.2 Model of a spraying nozzle:
1 – tube for material flow, 2 – nozzle, 3 – piezoceramic cylinder

Figure 2.2 shows the model of a spraying nozzle. Tube (1) directs the flow of material inside the spraying nozzle. Piezoceramic cylinder (3) directs the flow of material into the nozzle (2). Piezoceramics ensure that the spraying is performed in a controlled manner.

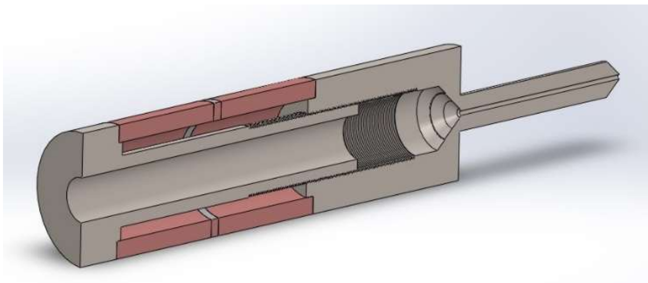

Figure 2.3 Section view of the nozzle

As seen in Figure 2.3 the material flow through the nozzle would have no obstacles – straight forward. However with addition of piezoelectric material in the middle, vibrations with high frequency are being obtained. This leads to a consistent droplet flow through the nozzle.

2.2.2. Piezoelectric nozzle

Manufacturing and testing of the spraying nozzle parts was supervised by Dr. A. Bubulis. Figure 2.4 shows the actual parts and assembly of the nozzle:

Figure 2.4 Individual parts and assembly of the nozzle

Piezoelectric material (brown rings) is soldered of 2 parts and has a conductive metal in the middle of these parts. A wire is connected to the metal and electricity is being discharged. The piezoelectric parts vibrate and transfer vibrations to the nozzle.

Parameters used during the test:

1. Voltage – 200V;
2. Vibration frequency – 50-65 kHz;
3. Both water and modelling liquid were used for the test.

After testing the model, several aspects were identified. The model of a nozzle is in a working condition and a desirable flow is obtained. However this is only possible while using a lower viscosity material – water.

On the other hand, problems occur using a material mixture – water with ceramics. The material mixture used in dentistry is clogging the model. Location of clogging is shown in figure 2.5.

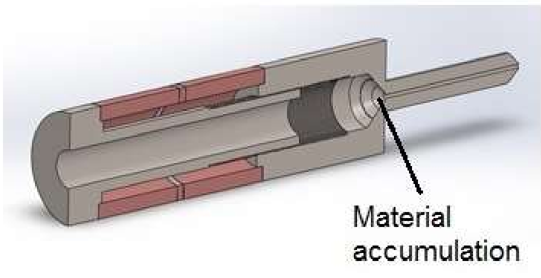

Figure 2.5 Section of clogging

Figure 2.5 shows that clogging starts in the narrowest point of the model, where a droplet flow is required. Material accumulation stops the flow entirely. It is then required to stop the process and clean the nozzle. This is very inconvenient since more time is spent for cleaning than it is spent for printing.

We can now conclude 2 main problems that need further research:

1. The design of the material is simple and operating result is obtained using liquid with low density. On the other hand when viscosity increases due to ceramic material added to water, the substance becomes too dense – nozzle gets clogged.
2. It is not possible to easily control the ratio of materials. Density of the mixture changes rapidly and it is not easy to determine what ratio in the mixture is available at the moment of the test.

This suggests that further analysis of the model is required. In addition improvements in dosing of the material is necessary to accomplish a desirable result.

3. FURTHER RESEARCH ON DENTAL CERAMICS AND SUGGESTED IMPROVEMENTS OF THE SYSTEM

3.1. Particle size of dental ceramics

First of all it is important to analyze whether it is actually possible to achieve a proper flow of material through the head of the nozzle. This is done by measuring particle sizes of the ceramic material. Figure 3.1 shows the measurements in progress.

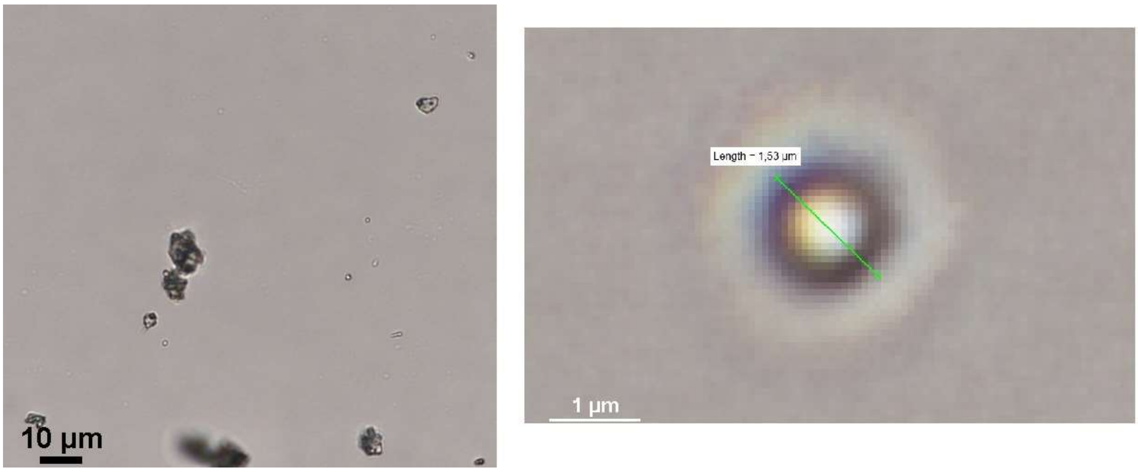

Figure 3.1 Measurement of ceramic particle sizes

After measuring sizes of particles the results were obtained. They suggest that particles vary in size of around 0.88 – 1.53 μm in diameter. By comparing it to the size of the nozzle, which is around 0.5 mm in diameter (or 500 μm), it is possible to conclude that individual ceramic particles would encounter no obstacles while passing through the nozzle.

In this case further analysis is required in order to understand what causes the clogging inside the nozzle.

3.2. Solubility of dental ceramics

Ceramics from Cerabien ZR was obtained and used for the successive experiment. The testing was divided between 6 plastic storage wares.

1. At first a specified amount of water was added into each storage ware. The amount of water was chosen assuming the concentration of ceramics and water will be 1:10 and 1:5.
2. Secondly a specified amount of ceramics was added into the plastic ware. At the point of pouring it seemed to be mixing well, but despite that it was mixed manually for several seconds.
3. Finally half of the storage wares were closed. This was done in order to see if detaching the mixture from air circulation has any effect on it.

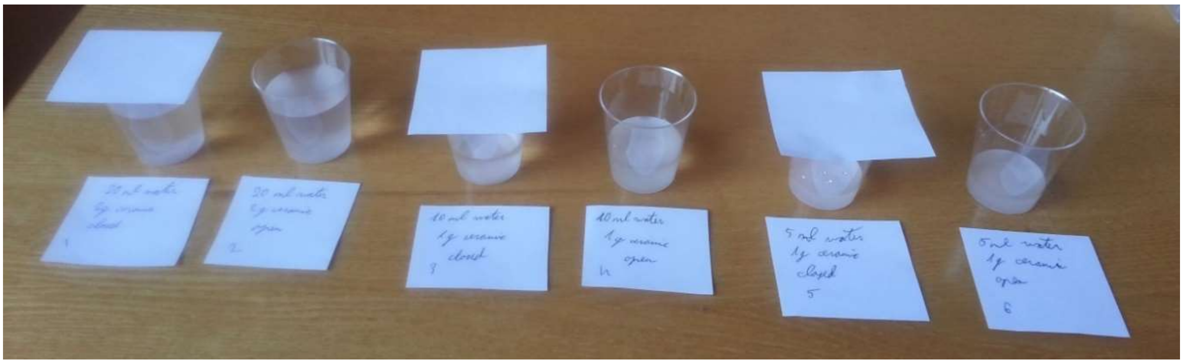

Figure 3.2 Experiment on ceramics behavior in water with time

After all storage wares had ceramics in it, the samples were left untouched for some time. The information gathered during the experiment is summarized in the table 3.1.

Information in Table 3.1 suggests that sedimentation occur in 15 minutes or less. Figure 3.3 shows the appearance of ceramics in water – clearly visible sediments at the bottom of the storage ware.

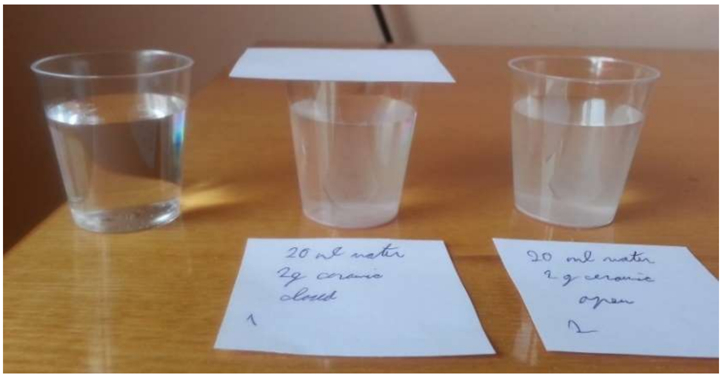

Figure 3.3 Visible sediments

Table 3.1 Summary of the experiment with ceramics

Sample No.	1	2	3	4	5	6
Water, ml	20	20	10	10	5	5
Ceramics, g	2	2	1	1	1	1
Hatch	Close	Open	Close	Open	Close	Open
Results after						
15 min	Visible sedimentation	Visible sedimentation	Visible sedimentation	Visible sedimentation	Visible sedimentation	Visible sedimentation
60 min	Clear sedimentation	Clear sedimentation	Clear sedimentation	Clear sedimentation	Clear sedimentation	Clear sedimentation
24 h	Full sedimentation (grimy water)	Full sedimentation (grimy water)	Full sedimentation (grimy water)	Full sedimentation (grimy water)	Full sedimentation (grimy water)	Full sedimentation (grimy water)

This means that very little time is available for proper spraying to occur. Figure 3.4 further shows how the particles of ceramic the material behave with respect to time:

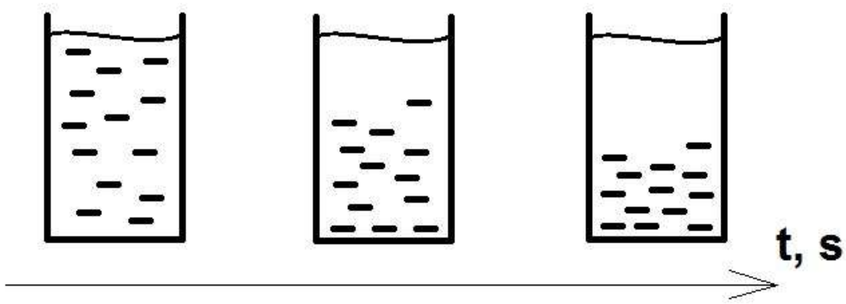

Figure 3.4 Location of molecules with dependence on time

Firstly, when the ceramic material is inserted into water, the particles of the ceramics move freely inside the container. Distribution of particles is equal between each part of the container.

Secondly, the external forces start to diminish and the impact of force of gravity increases. Heavy particles of the ceramics start to accumulate at the bottom of the container, while lighter particles of water rises to the top.

Thirdly, the external forces disappear and the force of gravity is the strongest force around the container. This forces all the ceramic particles to stay at the bottom rather than in between the water particles.

In this case a time passes by, the concentration of ceramics in the water diminish. At first we obtain close to 100% particle distribution in water which is the goal in this case. Unfortunately it starts to decrease just after mixing is finished. As time passes, the diminishing effect lowers, but the mixture not usable almost since the start.

It is clear that improvements are required in order to obtain a constant viscosity level throughout the mixture. Only then it is possible to proceed using material with the nozzle.

3.3. Improvements of the system

This chapter is dedicated for further development of the system for spraying. This is done by introducing improvements in dosing and mixing processes.

3.3.1. Suggestion for a piezo pump

Since the previously discussed model did not meet expectations, improvements need to be made. Further analysis of possible variants is required. Main idea of the piezoelectric pump is showed in figure 3.5.

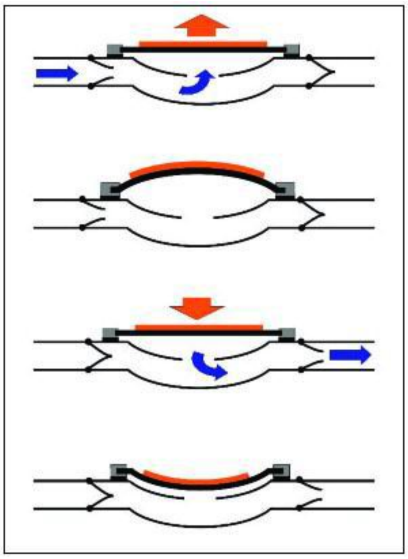

Figure 3.5 Piezoelectric pump [22]

In this case piezoelectric plate is mounted on the specified material. The material becomes mechanically stressed, when electrical impulse is provided to the piezoelectric plate. The material deforms and creates a space for the printing material flow to occur. After that material goes back to previous state, so the flow is canceled. This is repeated in high frequency, so small amount of material (droplet) passes each time [22].

3.3.2. Passive valve

In order to achieve a one sided material flow, passive valve is required. This is achieved using a membrane material inside in and out tubes. Figure 3.6 shows how the flow is achieved.

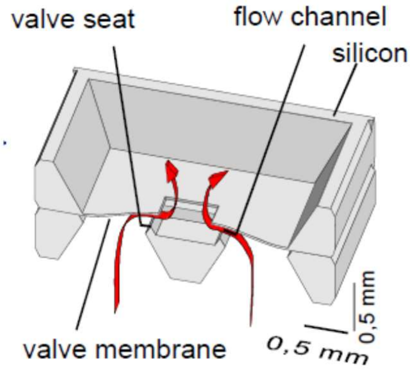

Figure 3.6 Passive valve [23]

From one side, printing material pushes on to the membrane and deforms it. A gap between the membrane and valve seat opens up. This allows the material to move through the tube. When the flow changes direction, the printing material pushes on to the membrane form the opposite side. The membrane is pushed on to the valve seat and gap is closed. Flow of material is negated to this side. After that the material is again pushed in different direction, membrane is separated from the valve seat and material flow is enabled again. Such cycle is repeated in high frequency, so it seems like a constant, one directional material flow [23].

A model of the passive valve required was generated using SolidWorks program. Figure below shows a section view of an open valve.

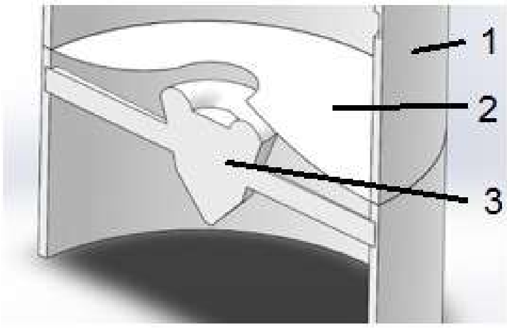

Figure 3.7 Model of a passive valve:
1 – tube for material flow, 2 – membrane material, 3 – valve seat

In case the material flow changes, the membrane (2) is pushed back on to the valve seat (3). This forces the membrane to close the tube (1) and the flow of material is suspended. After that the direction of flow changes back, the material pushes the membrane away from the valve seat and the material flow regenerates.

3.3.3. Model of a piezo pump

It is now possible to make a design of a piezo pump. Model of a pump was created and its section view is shown in Figure 3.8.

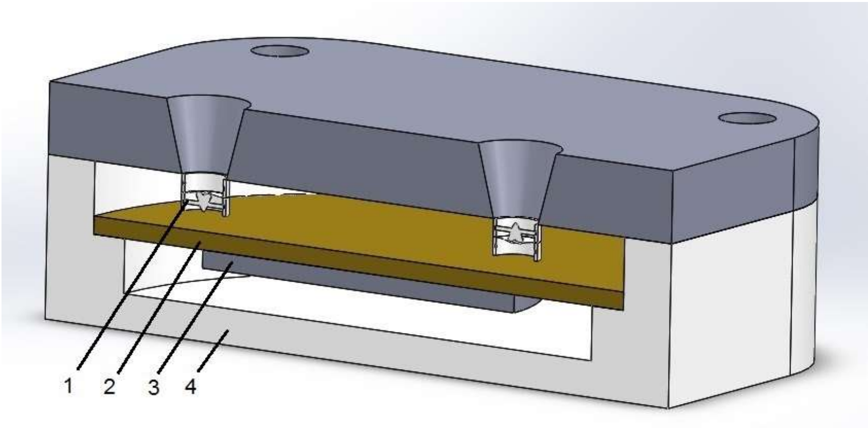

Figure 3.8 Section view of a piezo pump:
1 – passive valve, 2 – diaphragm, 3 – piezoelectric material, 4 – pump structure

Passive valve (1) directs the flow in and out of the pump. There are 2 holes for the material to travel – intake and outake. This is done so that the material is flowing rather than just bouncing in one place.

Diaphragm (2) pushes and pulls the material in and out of the pump. When the piezoelectric material deforms, the diaphragm is also deformed accordingly. This changes the volume in the cavity of the pump and thus pushes the material.

Piezoelectric material (3) deforms when electricity is applied to it. Since it is directly attached to the diaphragm, the diaphragm deforms as well. When electrical current is stopped, both piezoelectric material and diaphragm goes back to initial state.

Structure of the pump (4) assembles parts of the pump in a desired fashion. The case ensures that there are no leaks of the material and allows the piezoelectric material to vibrate.

3.4. Improvements of material dosing

In order to have a more thorough understanding about ceramics and how they behave in field, it is necessary to study a working example. Since it was not possible to find a similar example, IFO Sanitar ceramic manufacturing plant was visited instead. They produce ceramics for a private or public restroom – wall hung and standing wc's, washbasins and vanity tops.

Since it is a huge manufacturing plant, they follow certain processes for manufacturing the ceramic products. Figure 3.9 shows the scheme on how the production is performed at the factory:

Figure 3.9 Sequence scheme for manufacturing

It is clear that the material obtained has to go through a long process before it is possible to obtain a resulting product. By comparing it to our case it is now apparent that another step may be added before spraying the material through a nozzle – constant mixing. By doing so it is possible to obtain a consistent desnity of the material mixture.

3.4.1. Suggestion for a dosing mixer

Since the material accumulate in one section of the container rather than being distributed throughout it. In this case the mixing should be done at the time or just before spraying the material. As already explained in figure 1.13, there is a possibility to mix materials in a spiral doser.

At first each material (ceramics and water) are in separate containers. These containers, or at least the one containing liquid needs to have its temperature elevated. When the process begins, each material comes into the doser from separate intake channels. Piezoelectric vibrations will assist in mixing both materials. After the mixture travels through the spiral, it reaches the desired density and is sprayed through the outtake channel of the doser.

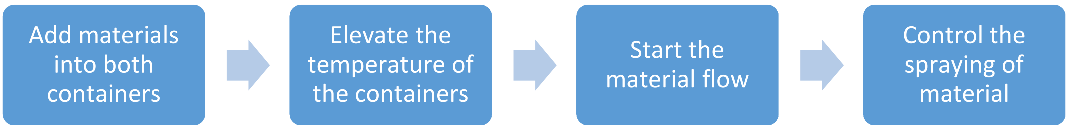

Figure 3.10 Sequence scheme for material dosing

This would lead to a constant level of ratio between ceramics and water for each droplet. Clogging is thus removed, if the material is mixed properly.

3.4.2. Model of a dosing mixer

After consultations, practical tasks and further research I have come up with the idea of how to combine supply of material and its mixing at the same time. Figure 3.11 shows a model for such task:

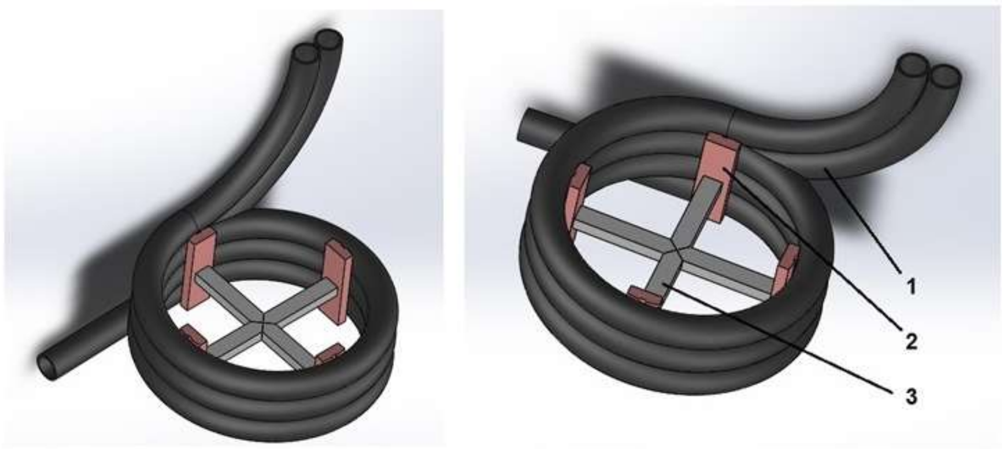

Figure 3.11 Model of a dosing mixer:
1 – tube for material flow, 2 – piezoceramic vibrators, 3 – support structure

Figure further explains the working principles of the model. The tube (1) has two intake channels. The upper channel is supplied with a mixing liquid (water). The lower channel is supplied with ceramic material. Electric impulse is provided to the piezo crystals (2), which are attached to a support structure (3). The electric impulse forces a vibration in piezo crystals, which in turn makes the tube to vibrate accordingly. Vibrations of the tube results in a motion of materials fed into the intake channels. Combination of motion and vibrations forces the material to mix and move out of the structure.

There is an outlet at the end of the tube, where the mix of materials flows out. The outlet may be then connected to the nozzle discussed in previous part of the work. This will combine both models to create a system with a preferable outcome.

3.4.3. Assembly of the system

At his point I already have solutions for a both piezo nozzle and dosing mixer. It is now possible to make an assembly of the parts. In addition I have added simple material containers for further clearance of the model. Figure 3.12 show the assembly of the system:

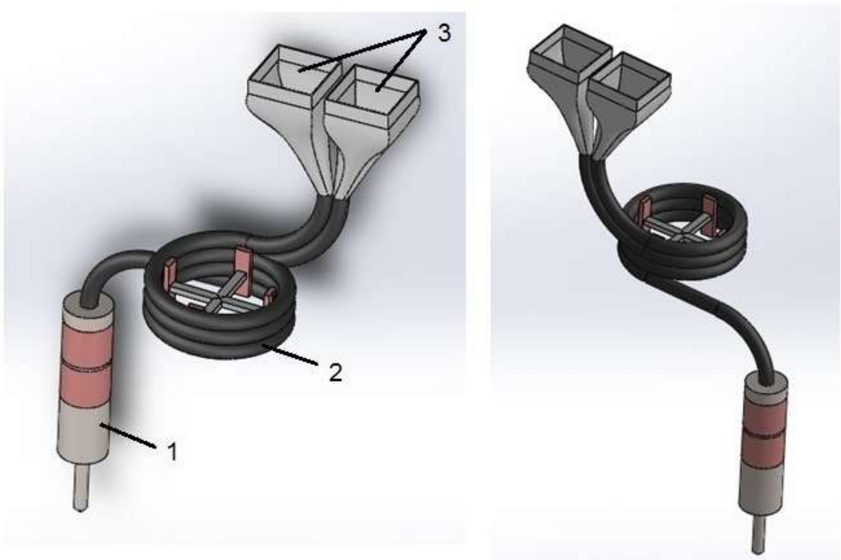

Figure 3.12 Assembly of the system:
1 – spraying nozzle, 2 – dosing mixer, 3 – material containers

Such system conveniently uses piezo ceramics for both mixing and spraying the materials. Using this method it should be possible to:

1. Mix materials properly;
2. Remove clogging of the nozzle;
3. Obtain a desirable spraying result.

In conclusion usage of piezoceramic materials for various parts of the process would result in a simple design which is capable of supplying a favorable outcome. Further research would cover development of a working prototype and testing it.

4. ANALYSIS OF ECONOMIC BENEFITS REGARDING USAGE OF TECHNOLOGY PROVIDED

In this chapter prices for materials are analyzed. Parts of the chapter include research on correlations between prices of materials, end products and manual labor costs.

4.1. Material price analysis

First of all, it is important to determine what is available in the market and prices for the materials. Skillbond.com and Ebay.com were used in order to identify the market supply. Table 4.1 shows the results [24].

Table 4.1 Summary of material price analysis

Categories	1	2	3	4	5	6	7	8	9	10
Material, g	200	200	10	50	50	10	50	50	200	70
Price, €	131.54	153.47	14.32	57.65	64.53	14.32	57.65	69.50	227.12	112.67
Price for 200g, €	131.54	153.47	286.40	230.59	258.14	286.40	230.59	278.01	227.12	321.91

Material, g – amount of material in the package;

Price, € – price for the package;

Price for 200g – price for 200g of material in given packages.

It is important to notice that lowest prices were indicated in North America, while highest prices were in Europe. There is also a possibility that similar or identical products are available for Asian markets in lower prices than identified here. Despite that we assume to use only prices for specified areas.

It is now possible to analyze the information provided – a graph was constructed for further comparison of the price levels available. Figure 4.1 shows the correlation between price and package of the material required.

After taking a closer look at the graph it is possible to distinguish that there is no actual correlation between the price and amount of the material. In some cases (categories 1 and 2) the material price is relatively low, while in other cases (categories 9 and 10) – relatively high.

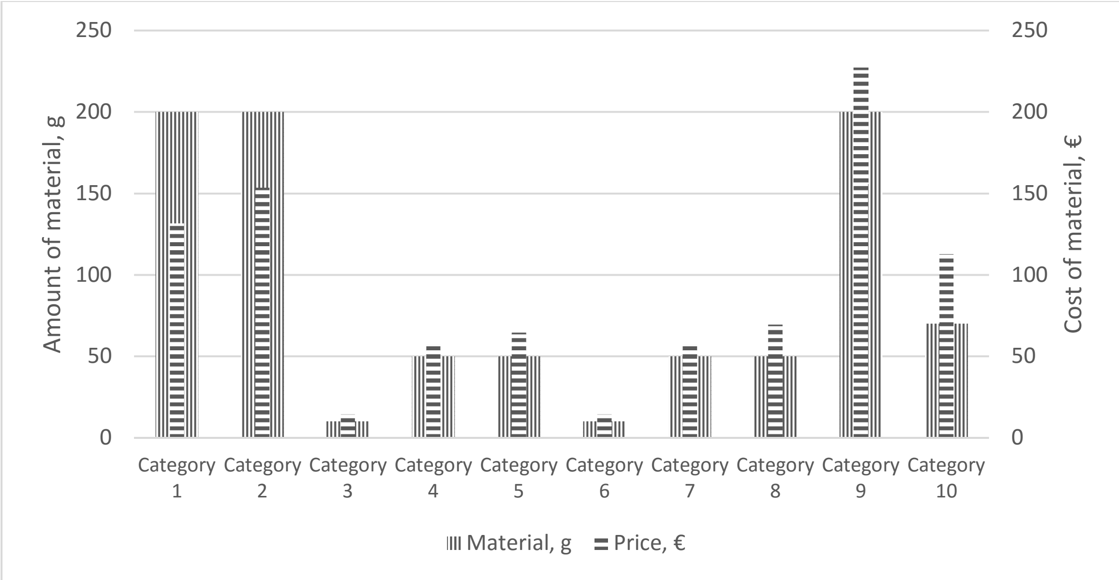

Figure 4.1 Correlation between price and amount of material

Using the information provided we may conclude that:

1. Average price for 200g = 240.42 €
2. Average price for 1g = 1.20 €

Now we know the average price for ceramics in the market. But in our case the customer of such product is a dental technician or rather a company working in the field of dental crowns. This means that the buying price for a company will be around 50% less than the retail price. Even though we assume that a company pays full price for the product.

In addition it is important to know the price of the material used for a dental crown. The weight of an average dental crown is 2g. This means that the end result will weigh 2g, but we can assume that a technician will make mistakes and use more material than required. In such case we suggest that 5g of ceramics will be used in order to make a dental crown. This leads to the price of material for a dental crown, which will be 6 €.

4.2. Product price analysis

It is now important to determine prices for the final products – dental crowns. Fortunately stomatology clinics offer full pricelists for their services regarding dental caps. Internet websites of stomatology clinics were chosen by random and the information extracted from their pricelists is shown in table 4.2.

Table 4.2 Summary of product price analysis

Stomatology clinic pricelist	1	2	3	4	5	Average
Metal crown, €	197	200	380	350	230	271.4
Zirconia crown, €	319	400	520	580	300	428.8

First of all it is possible to compare the difference between the prices between metal and zirconia crowns. It is clear that metal crowns are easier and cheaper to produce, thus the product cost less.

On the other hand ceramics have a higher price in the market. An average price of zirconia ceramic crown is 428.8 €, which is 58% more than the price of a metal crown. This is a significant difference only comparing the basic purpose any dental crown – to serve as a tooth.

4.3. Price comparison and distribution

It is now possible to compare the price of material with the price of the final product. The material itself for a dental crown will cost 6 €, while the final result in a mouth of a patient will be priced at 428.8 €. This is a huge increase in cost – 71 times more than the material costs. But such comparison does not reflect on how much the cost increases while the material is being processed, a crown is manufactured and ceramic is inserted into the mouth of a patient.

In this case further expenses need to be added to better understand the ratio between profit and loss. Several other aspects are added into the comparison: other materials besides ceramics (modelling liquid), equipment required for production, office space (rent), transportation of materials, costs of work of a technician and a dentist.

There are several important aspects to take into account:

1. Ceramics used for manufacturing a ceramic crown will remain constant and thus the price is constant. Same applies to complementary materials.
2. Since the production does not revolve around single numbers, the cost of equipment, office space and transportation is distributed between many elements produced, so the prices will be comparatively low.
3. Each crown will required couple hours of manual work by both dentist and technician, so this will be taken into account accordingly.

Table 4.3 shows how the costs are distributed between several process steps. This is important since the cost of ceramic structure will mostly depend on costs of manual labor rather than materials and transportation.

Table 4.3 Cost distribution

Cost distribution	Ceramics	Other materials	Technician	Dentist	Equipment	Office	Transportation	Total
Price, €	6	6	150	254.8	4	4	4	428.8
Percentage, %	1.4	1.4	35	59	0.9	0.9	0.9	100

A pie chart is used to further explain the situation. The given chart suggests that the biggest part of financing falls into categories of dentist and technician. This means that around 59 % goes to the work of the dentist and around 35 % goes the technician. Summing it up 94 % of money spent from scratch to finished product in use is intended for manual labor of specialists.

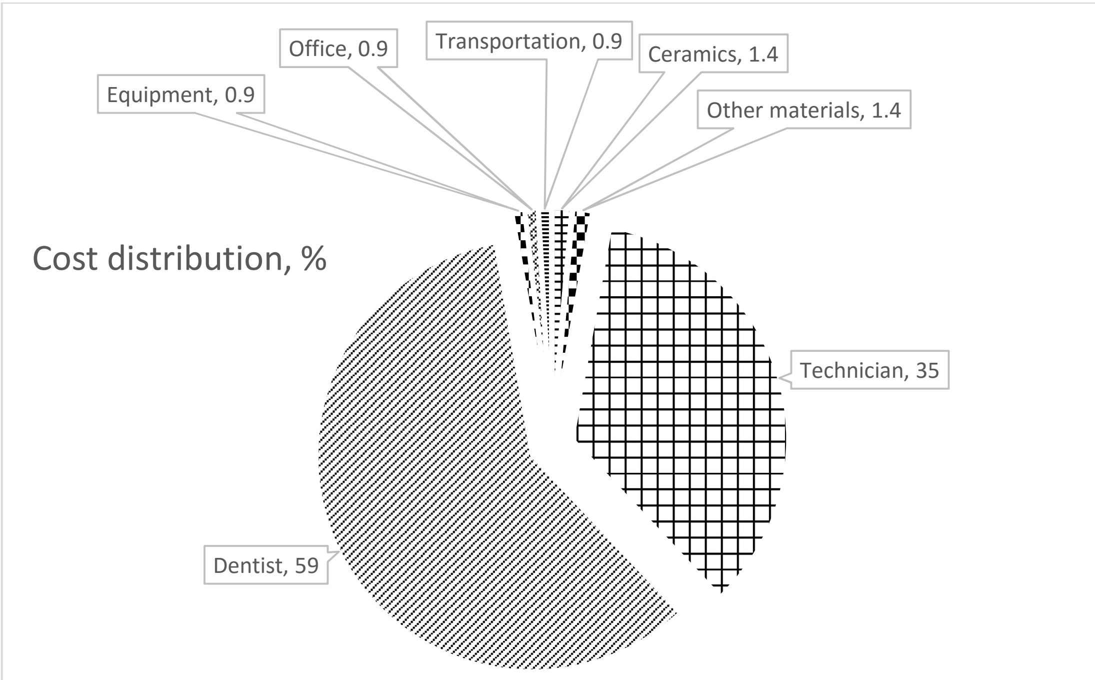

Figure 4.2 Cost distribution for the final product

This suggests that it is possible to cut the price of the final product drastically by reducing the time that the well paid specialists spend on it. In this case it is possible to reduce costs by changing from manual labor to automated machining.

On the other hand changing from a technician to a machine will probably require an operator the work the machine. But in this case an operator may produce huge amounts of products and even work several machines at the same time. In this case the work required is distributed infinitely thus the price is diminished accordingly.

By proceeding with such method it would be possible to reduce the cost percentage from 35 % to just 4 % (same as transportation and equipment costs). In this case a reduction in price from 428.8 € to 282.8 € is available. Furthermore such price would also be very competitive towards metal crowns (271.4 €).

To sum it up the introduction of automated machinery would result in a drastically reduced prices of the production and make it competitive towards other cheaper solutions that are currently available.

CONCLUSIONS

1. After the investigation it is possible to conclude that the subtractive manufacturing methods for dental ceramics are quite developed and available. On the other hand there is not much progress present in the additive manufacturing field. There are plenty of methods to choose from, but each present difficulties on adjusting the technology to meet requirements of ceramic materials.
2. After the analysis of possible solutions for spraying it may be concluded that piezoelectric vibrations could be used to assist the process. On the other hand material difference between dental ceramics and plastic based materials used in additive manufacturing is apparent. There is no straightforward possibility to use the desirable material with a selected technology.
3. After testing of the ceramic material several aspects were revealed. First of all ceramic particle size is sufficiently small, so it is possible to use the material with ceramic nozzles available. Secondly ceramics does not properly mix with liquids, so it is problematic to obtain a desirable mixture which could be properly used with the said nozzles.
4. By adding a dosing mixer into the spraying system there is a possibility to improve solubility of ceramics and thus obtain a desirable mixture of materials. In such case a mixture passes the nozzle properly and is sprayed further in a required state. Further development and addition of other systems would then become a possibility.
5. After the examination it is possible to conclude that such a system would be economically beneficial. First of all it would decrease the production time of a dental structure and thus increase the volume of production. Secondly the technician/operator would use machinery, which in turn made his work more efficient and less costly. Thirdly reduction in costs would decrease the price of the product, thus making it more competitive and attractive for the market.

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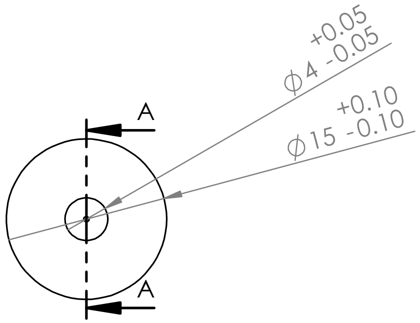
APPENDICES

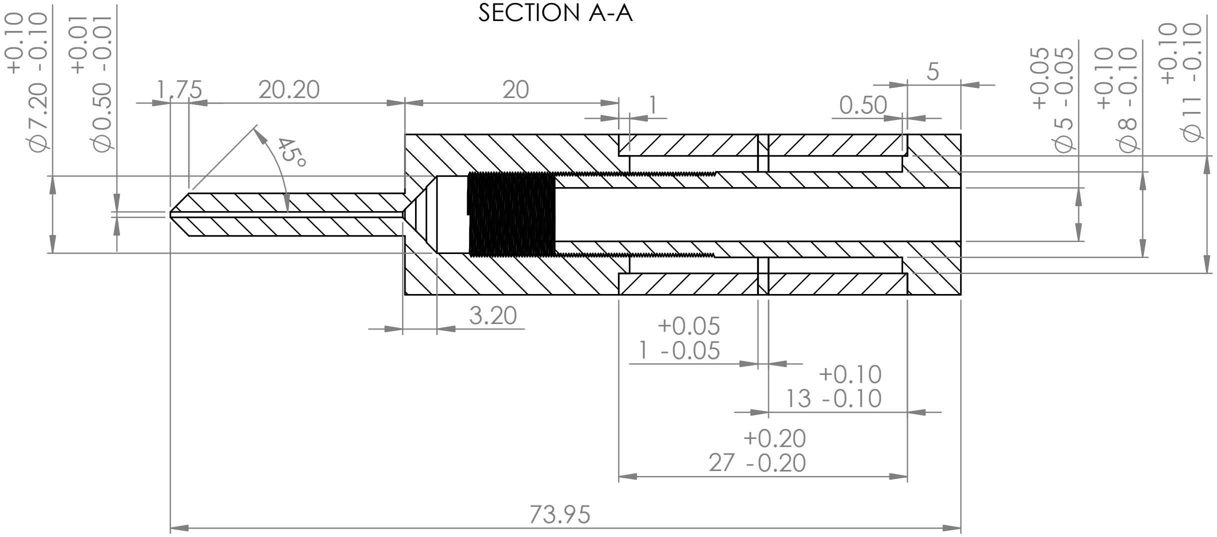
1. Appendix No. 1. Objet30 specifications
2. Appendix No. 2. Model of a spraying nozzle
3. Appendix No. 3. Model of a piezo pump
4. Appendix No. 4. Model of a dosing mixer

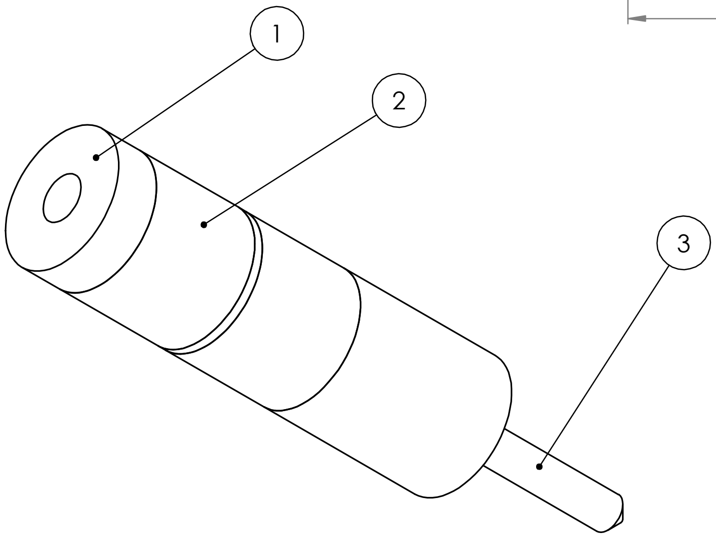
Appendix No. 1. Objet30 specifications

Model materials	• Rigid Opaque white (VeroWhitePlus); • Rigid Opaque blue (VeroBlue); • Rigid Opaque black (VeroBlack); • Rigid Opaque gray (VeroGray); • Polypropylene-like (DurusWhite)
Support material	FullCure 705 non-toxic gel-like photopolymer support
Material cartridges	Sealed four 1 Kg (2.2 lbs) cartridges
Net build size	294 x 192 x 148.6 mm (11.57 x 7.55 x 5.85 in.)
Layer thickness	28 microns (0.0011 in.)
Build resolution	X-axis: 600 dpi; Y-axis: 600 dpi; Z-axis: 900 dpi
Accuracy	0.1 mm (0.0039 in.) may vary depending on part geometry, size, orientation, material and post-processing method
Size and weight	Machine: 82.5 × 62 × 59 cm (32.28 × 24.4 × 23.22 in.); 93 kg (205 lbs); Tray size: 300 × 200 × 150 mm (11.81 × 7.87 × 5.9 in.)
Workstation compatibility	Windows XP, Windows 7, Windows 8
Network connectivity	Ethernet TCP/IP 10/100 base T
Jetting heads	2 printing heads; SHR (Single Head Replacement)
Power requirements	Single phase: 100-120V~; 50-60Hz; 7A 200-240V~; 50-60Hz; 3.5A
Regulatory compliance	CE/FCC/RoHS
Operational environment	Temperature 18 C-25 C (64 F-77 F); relative humidity 30-70 % (non-condensing)

Appendix No. 2. Model of a spraying nozzle



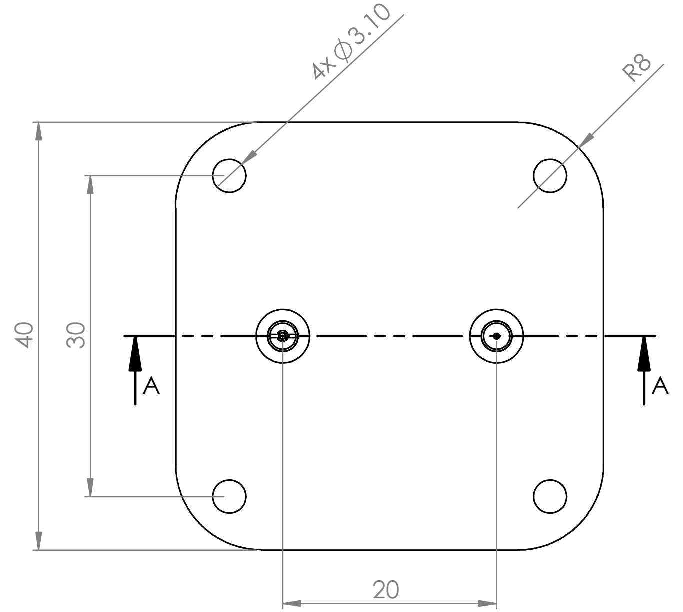


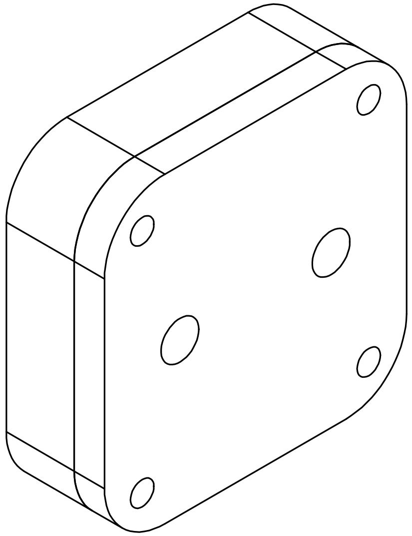


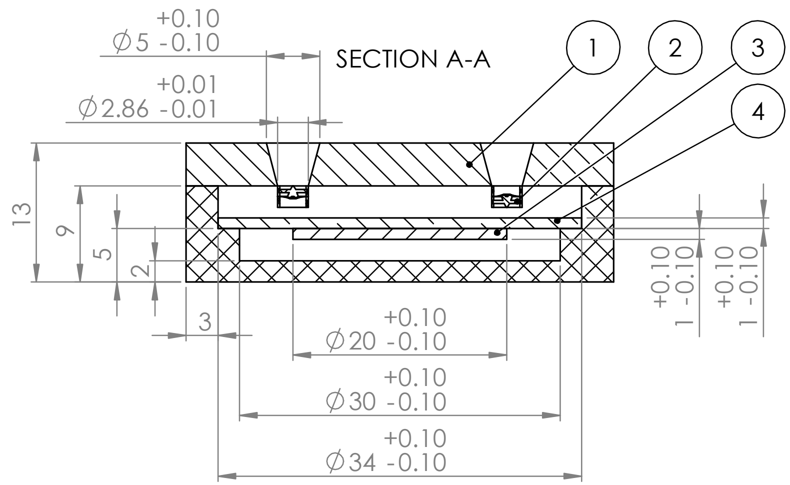
PART NO.	PART NAME	DESCRIPTION	QTY.
1	Vibratory tube	Direct the material flow	1
2	Piezoceramic cylinder	Create material flow in the structure	1
3	Nozzle	Spray the material	1

Department of Production Engineering	Technical reference	Document type: Assembly drawing	Document status: Research project
Legal owner: KTU	Created by: Ignas Tepcovas	Title: Piezoelectric nozzle	EG 16.05.01 AD
	Approved by: Assoc. prof. dr. Marius Rimašauskas		Rev.: A; Date: 2016-05-15; Lang.: En; Sheet: 1/1

Appendix No. 3. Model of a piezo pump



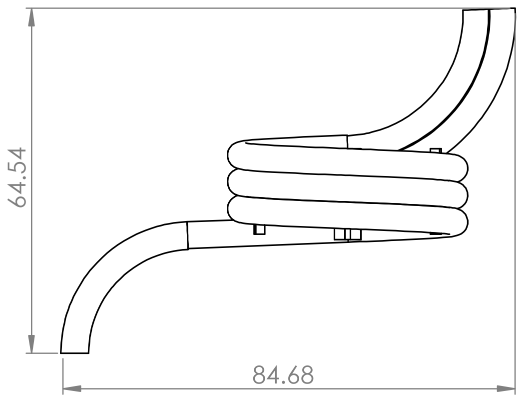


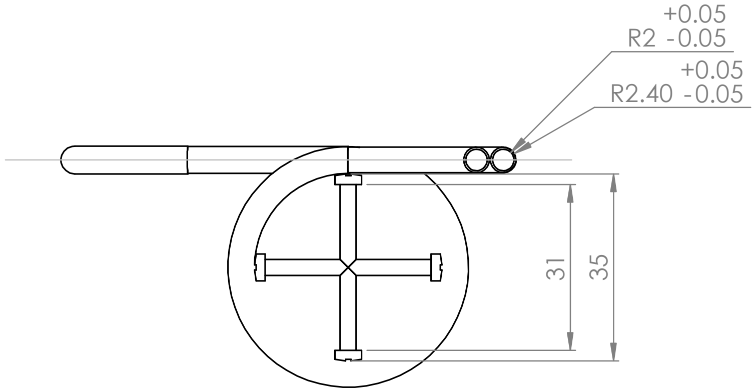


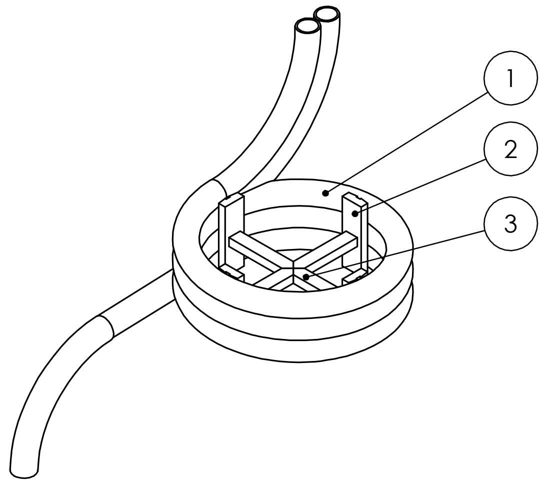
PART NO.	PART NAME	DESCRIPTION	QTY.
1	Case of the pump	Assembles parts of the pump	1
2	Passive valve	Directs flow of material	2
3	Piezoelectric material	Deforms with electricity applied	1
4	Diaphragm	Pushes material in and out	1

Department of Production Engineering	Technical reference	Document type: Assembly drawing	Document status: Research project
Legal owner: KTU	Created by: Ignas Tepcovas	Title: Piezo pump	EG 16.05.02 AD
	Approved by: Assoc. prof. dr. Marius Rimašauskas		Rev.: A / Date: 2016-05-15 / Lang.: En / Sheet: 1/1

Appendix No. 4. Model of a dosing mixer







PART NO.	PART NAME	DESCRIPTION	QTY.
1	Tube	Directs material flow	1
2	Piezo vibrator	Electrically responsive material used to force the material mixing and flow	4
3	Support structure	Assembles parts	1

Department of Production Engineering	Technical reference	Document type: Assembly drawing	Document status: Research project			
Legal owner: KTU	Created by: Ignas Tepcovas	Title: Dosing mixer	EG 16.05.03 AD			
	Approved by: Assoc. prof. dr. Marius Rimašauskas		Rev.: A	Date: 2016-05-15	Lang.: En	Sheet: 1/1