NEW TECHNIQUE OF PRODUCING REMOVABLE COMPLETE DENTURE USING RAPID TOOLING APPROACH

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ABSTRACT

This thesis presents the development of a new approach for denture fabrication process by implementing the techniques used in the advanced manufacturing technology involving Computer Aided Design (CAD) and Rapid Tooling (RT) process. A 3D-ATOS scanning system was used to obtain the surface data of the edentulous model, occlusion rims of the patient and the teeth set received from the dental clinic. The scanned surface was refined using the Geomagic Studio 10 and then converted to IGES format for CAD application. A SolidWork version 2010 was used for designing reference lines, imaginary plane and setup curves to the 3D images of the scanned components. This was used as a reference for denture assembly in which, the design were followed to the occlusion and teeth arrangement principles and the data would then be stored in a CAD library for future design. Then maxilla anterior, maxilla posterior and mandible anterior teeth were assembled one by one while mandible posterior teeth were assembled by collision detection. Chewing detection was also conducted to check the contact region between upper and lower teeth by using interference detection technique. Then, new freeform surfaces were created for gingival and base plate. The complete dentures design were converted to STL format for production of master pattern using the Multi Jet Modelling (MJM) machine, one of the rapid prototyping (RP) technique. The pattern was used in the silicon rubber mould for vacuum casting process. Cold cure acrylic resin (VERTEX, Castavaria) was used as the denture material and casted in the silicone mould. Different degassing times were studied to reduce porosity dentures parts. Then, the final dentures were polished and tested on edentulous model to test the bite and adaptability. The finished denture was tested on patient edentulous to ensure the adaptability and comfortability. The result for the denture was found to be satisfactory and has good accuracy. While, from mechanical properties result was found the cold cure material which produced from the vacuum casting process has

32% higher the flexural strength than cold cure material processed from conventional technique (compression flask).

ABSTRAK

Tesis ini menerangkan tentang pembangunan pendekatan baru terhadap proses fabrikasi gigi palsu dengan melaksanakan teknik-teknik yang digunakan dalam teknologi pembuatan termaju yang melibatkan *Computer Aided Design* (CAD) dan *Rapid Tooling (RT)*. Satu sistem pengimbas 3D-Atos telah digunakan untuk mendapatkan data permukaan model *edentulous, occlusion rims* daripada pesakit dan juga set gigi yang diterima daripada klinik pergigian. Permukaan yang siap diimbas telah diperbaiki dengan menggunakan Geomagic Studio 10 dan kemudiannya ditukar kepada format IGES untuk aplikasi CAD. Perisian SolidWork versi 2010 digunakan untuk merekabentuk garis rujukan, paksi khayalan dan lengkung persediaan untuk imej 3D bagi komponen-komponen yang telah diimbas. Ianya dijadikan sebagai rujukan untuk pemasangan gigi palsu di mana, data rekabentuk berdasarkan prinsip *occlusion* dan prinsip penyusunan gigi ini akan disimpan di perpustakaan CAD untuk persediaan merekabentk gigi palsu yang seterusnya. Kemudian, semua gigi anterior atas, posterior bawah dan anterior bawah disusun satu persatu, manakala gigi poserior bawah dipasang menggunakan kaedah *collision detection*. Pengesanan mengunyah juga telah dijalankan untuk memeriksa kawasan sentuhan di antara gigi atas dan bawah dengan menggunakan kaedah *Interference detection*. Kemudian *freeform* pada permukaan baru telah diwujudkan untuk merekabentuk *gingival* dan tapak pada gigi palsu. Reka bentuk gigi palsu yang lengkap telah ditukar kepada format STL untuk penhasilan *master pattern* menggunakan mesin *MultiJet Modelling (MJM)* iaitu salah satu teknik *Rapid Prototyping (RP)*. *Master pattern* telah digunakan dalam acuan getah silikon untuk proses vakum. Bahan akrilik jenis rawatan sejuk (Vertex, Castavaria) telah digunakan sebagai bahan gigi palsu dan telah dituang mengikut acuan silikon. Perbezaan tempoh nyahgas pada bahan akrilik telah dikaji untuk mengurangkan keliangan pada bahagian-bahagian gigi palsu. Kemudian, gigi palsu digilap dan diuji ke atas model *edentulous* untuk menguji

gigitan dan kebolehsuaiannya. Gigi palsu telah siap diuji pada edentulous pesakit untuk menentukan kebolehsuaian dan keselesaannya. Hasil pemasanagn gigi palsu tersebut didapati memuaskan dan juga mempunyai ketepatan yang baik. Manakala, keputusan daripada sifat mekanikal mendapati bahan rawatan sejuk yang dihasilkan daripada proses tuangan vakum memperolehi kekuatan lenturan 32% lebih tinggi berbanding bahan rawatan sejuk yang diproses menggunakan teknik konvensional (mampatan kelalang).

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LIST OF ABBREVIATIONS

AMT	-	Advance Manufacturing Technology
CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
3DP	-	3 Dimensional Printers
RT	-	Rapid tooling
RP	-	Rapid prototyping
CNC	-	Computer Numerical Control
RS	-	Rafael and Saide
FRP	-	Fiber Reinforced Plastic
DDM	-	Digital Denture Manufacturing
ACT	-	Abrasive Computer Tomography
CT	-	Computer Tomography
STL	-	Standard Tessellation Language
SLA	-	Stereolithography Apparatus
RM	-	Rapid Manufacturing
MJM	-	Multi Jet Modelling
ABS	-	Acrylonitrile Butadiene Styrene
PMMA	-	Poly methyl methacrylate
PU	-	Poly Urethane
UV	-	Ultra Violate
FDA	-	Food and Drug Administration
ATOS	-	Advanced Topometric Sensor
CAE	-	Computer Aided Engineering
IGES	-	Initial Graphics Exchange Specification
STEP	-	Standard Exchange Product
POP	-	Plaster of Paris

FDM	-	Fused Deposition Modelling
SLS	-	Selective Laser Sintering
LOM	-	Laminated Object Manufacturing
EBM	-	Electron Beam Melting
RSP	-	Rapid Solidification Process
DLF	-	Direct Laser forming

DEFINITION OF TERMINOLOGY

Mesial	-	Side of a tooth is the side closest to the centre of the mouth
Distal	-	Side of a tooth is the side furthest from the centre, which is also the opposite of mesial
Contact point	-	The point on the proximal surface where two adjacent teeth actually touch each other is called a contact point
Occlusal	-	The occlusal surface is the broad chewing surface found on posterior teeth (bicuspids and molars)
Occlusion	-	The relationship between the occlusal surfaces of maxillary and mandibular teeth when they are in contact
Occlusal plane	-	Maxillary and mandibular teeth come into centric occlusion and meet along anteroposterior and lateral curves. The anteroposterior curve is called the Curve of Spee
Sagittal plane	-	An imaginary plane that travels vertically from the top to the bottom of the body, dividing it into left and right portion
Prosthodontics	-	Known as dental prosthetics or prosthetic dentistry, it is dental specialty pertaining to the diagnosis, treatment planning, rehabilitation and maintenance of the oral function, comfort, appearance and health of patients with clinical conditions associated with missing or deficient teeth and/or oral and maxillofacial tissues using biocompatible substitute.
Posterior teeth	-	The teeth in the back of mouth.
Anterior teeth	-	The teeth in the front of mouth
Alveolar ridge	-	The bony ridge of the maxilla or the mandible that contains the alveoli of the teeth
Labial	-	The labial is the surface of an anterior tooth that faces toward the lips

Buccal	-	The surface of a posterior tooth that faces toward the cheek
Palatal	-	Palate is the general area of the roof of mouth at upper teeth area
Ligual	-	This is the side of either your upper or lower teeth that is -opposite the facial side, or the side that people do not see when you smile. Lingual refers to the tongue side of the tooth
Vestibules	-	Any of various bodily cavities especially when serving as or resembling an entrance to some other cavity or space as the part of the mouth cavity outside the teeth and gums.
Anteroposterior	-	From front to back. When a chest x-ray is taken with the back against the film plate and the x-ray machine in front of the patient it is called an anteroposterior (AP) view
Esthetics	-	(art) the branch of philosophy dealing with beauty and taste (emphasizing the evaluative criteria that are applied to art)
Phonetics	-	This is a branch of linguistics that comprises the study of the sounds of human speech, or in the case of sign languages
Stomatognathic	-	denoting the mouth and jaws collectively.

CHAPTER 1

INTRODUCTION

1.1 Background of study

Denture is used to replace the damage, lost or removed tooth for human. There are few types of dentures which have been classified as removable complete denture or some time called as full denture, partial denture and over denture. The complete denture is used for people missing all teeth and the partial denture and over denture both are adaptations of the basic process in the removable complete denture. Reported from Malaysia Ministry of Health, in Malaysia have 3 millions denture user and among the highest in Asia. Where, about 58 percent is elderly more than 50 years (KKM, 2003). Currently, the elderly population those aged 60 and above has increased due to a longer life expectancy, the quality of life and better medical facilities (Ibrahim, 2011) . Following that, the denture demand has increased from year to year. Therefore, the development of complete denture was selected as a case study in this research. In addition, a new approach for denture fabrication was studied in order to solve some problems observed in the conventional technique.

The aim of this research is to explore new way of producing denture by integrating the techniques used in the advanced manufacturing technology (AMT) such as 3D scanning system, computer-aided design (CAD), rapid prototyping (RP) and rapid tooling (RT). Many efforts have been carried out to improve the denture process, including the development of a new CAD system for denture design

(Yuchun Sun *et al.*, 2009) and the integration of CAD/CAM & CNC for denture teeth fabrication (Chang and Chiang, 2002;Chang and Chiang, 2003). There was also a development in rapid manufacturing for implant framework directly using selective laser melting (SLM) by (McAlea *et al.*, 1997;Gideon *et al.*, 2003;Over *et al.*, 2002). Although progress has already been reported elsewhere in the literature concerning the design and fabrication, significant gaps in knowledge are still existed. None is devoted to use vacuum casting technique for the fabrication process. Furthermore, this research also contributes in developing denture teeth set library which can be shared by any commercial CAD system.

1.2 Objectives of study

This study embarks on the following objectives;

i. To evaluate the process ability and mechanical properties of the existing denture material produced using vacuum casting and conventional technique.
ii. To apply the dental principles in designing the removable complete denture using computer aided design (CAD) system.
iii. To fabricate the removable complete denture using rapid tooling (RT) approaches.

1.3 Scope of the study

The scopes of this study are;

i. Vacuum casting process was used as a manufacturing method to produce the removable complete denture.
ii. Cold cured or self cured acrylic resin was used as the denture base material.
iii. Standard commercial denture teeth set were used in the denture system.
iv. 3D-ATOS scanner system was used as digitizing device for edentulous model, occlusion rims and denture teeth.
v. Commercial SolidWork CAD software was used in the virtual design and assembly.
vi. Multi Jet Modelling technology (ProJet SD3000) was used to produce denture model.
vii. MCP4-01, the vacuum casting machine was used in the rapid tooling fabrication process.

1.4 Problem statement

Currently, the removal complete denture is still being produced manually at every dental clinic laboratories and manufactured using conventional techniques via compression flask or injection moulding process. The process requires many steps and mostly related to labour intensive work. A good quality of the complete denture was rated by prosthodontists at 2 to 6 months to be produced. Besides that, information related to personalize denture cannot be retrieved for denture replacement. A large space for storage is also required to process each of denture parts. In addition, high skills personals are normally needed in wax carving and teeth arrangement, in which the denture quality depends mostly on the dental technologist subjective judgment.

Therefore, an appropriate system is needed to solve the issues from the current process. The proposed idea is to use a computer system in the data acquisition, denture design and assembly as well as using the rapid tooling technique for the fabrication process.

1.5 Significant of study

The study is significantly importance for the future of dental technology. Most of the current trends practice by the industry players in designing and manufacturing are trough the helped of computer system. Therefore, this research will contribute to the development of computer based system in dental technology area. The new process will minimize the current dental laboratories' procedures as well as patient visiting time and expenses. The used of CAD system in design will reduce the dependency of high skill people in wax craving and teeth assembly. The design task can be carried out anywhere and not really depend on location or lab facilities. These will reduce whatever cost related to the existing laboratory setup and storage area. The new procedure is expected to produce a complete denture within a week hence a significant reduce in the process lead time as compared to the current procedure. The use of rapid tooling in the fabrication process will enhance the fitting accuracy and reduce the fabrication time. The mould can also reproduce denture and for denture replacement process without repeating the procedure as used in the conventional process.

1.6 Thesis outline

On the following chapter, the introduction of the denture basic principles, denture types and denture manufacturing process are presented. Information on rapid prototyping and rapid tooling system will be discussed. Chapter 3 presents the methodology and process used in the design and fabrication of denture component. Chapter 4 presents the result and discussion. Chapter 5 offers conclusion and recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents a literature review of conventional fabrication technique of removable complete denture as well as the advanced technique. It also reviewed the materials, tools and method that used in the denture fabrication process. In the advanced manufacturing technology (AMT), the basic principle of the layer manufacturing technology in rapid tooling (RT) and CAD were discussed.

2.2 Types of denture

Denture has been classified into several types such as removable complete denture or known as full denture, where it is useful for a person missing all teeth (Singla, 2007). Another types is a fixed partial denture used for the person missing some of the teeth but still having a number of natural teeth (Pahlevan, 2005). A implant over denture is a denture that used precision dental attachment that can be placed in tooth roots that have been saved or placed into dental implants which the surgically placed the cylindrically shape of pore titanium (Vecchiatini *et al.*, 2009). Figure 2.1 shows the three types of denture.

a) Removable Complete Denture   b) Removable Partial Denture   c) Implant Over Denture

Figure 2.1: Types of denture (Deadwood, 2008)

2.2.1 Removable complete denture

Removable complete denture is a dental prosthesis which replaces the entire dentition and associated structures of the maxilla and mandible. A complete denture functions to restore aesthetics, mastication and speech. For aesthetic reasin, the complete denture should restore the lost facial contours, vertical dimension and so on. While, a complete denture should have good balanced occlusion in order to enhance the stability of the denture for functionally (Mastication). Then the phonetics is one of the most important functions of a complete denture is to restore the speech of the patient (Veeraiyan *et al.*, 2009;Robert, 2005).

2.2.2 Parts of removable complete denture

Removable complete denture has various parts and surfaces such as denture base (1), flange of denture (2), border of denture (3), denture teeth (3) and denture border as shown in Figure 2.2. Denture base is defined as part of a complete denture which rests on the oral mucosa and to which teeth is attached. It is usually made of acrylic resin. In some cases, the denture base made of metal is used to form the foundation of the denture. The denture base helps to distribute and transmit all the forces acting on the denture teeth to the basal tissues. It also has maximum influence on the health of the oral tissues. Moreover, it is the part of denture which responsible for retention and support (Veeraiyan *et al.*, 2003).

The flange of a denture defined as the essentially vertical extension from the body of the denture into one of the vestibules of the oral cavity. It has two surfaces, namely, the internal basal seat surface and the external labial or lingual surface. The functions of the flange include, providing peripheral seal and horizontal stability to the denture. Other of that denture border defined as the margin of the denture base at the junction of the polished surface and the impression surface. It is responsible for peripheral seal. The denture border should be devoid of sharp edges and nodules to avoid soft tissue injury. Overextended denture borders can cause hyper-plastic tissue changes. On the other hand, the border should not be under extended as peripheral seal may be lost. Lastly, the denture tooth is the most important part of the complete denture from the patient's point of view. The functions of the denture teeth are aesthetics, mastication and speech. They usually made from acrylic resin or porcelain (Veeraiyan *et al.*, 2003).

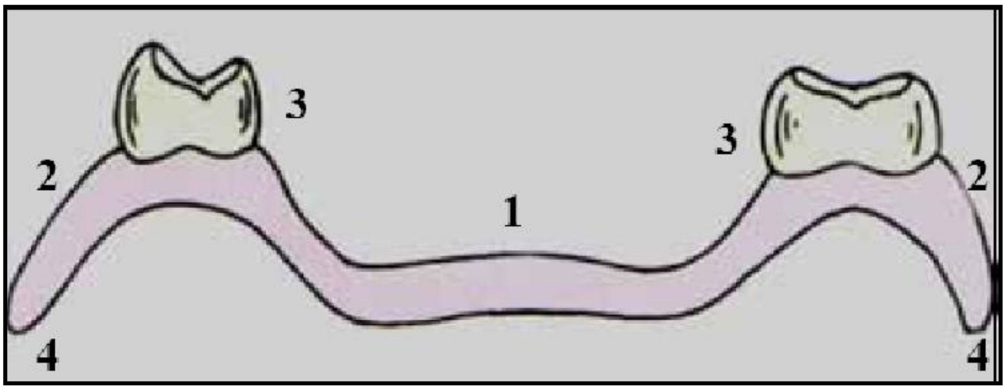


Figure 2.2: Surface parts of a complete denture (1) Denture base (2) Denture flange (3) Denture teeth (4) Denture border (Veeraiyan *et al.*, 2003)

2.3 Occlusal and teeth arrangment principles

Occlusal and teeth arrangement principles are very important in preparation of denture setup. In occlusal principles, it depends on anterior guidance which refers to the dynamic relationship of the lower anterior teeth against the lingual contours of the maxillary anterior teeth in centric, long centric and in their protrusive, lateroprotrusive, and lateral excursions. Together with centric relation and vertical dimension, anterior guidance must be regarded as the most important factor in reconstructing the stomatognathic system (Jambhekar *et al.*, 2009). Related of that, **APPENDIX A** show the principles of occlusion from simplified the occlusal concept for complete denture. While, the teeth arrangement principles show in **APPENDIX B** is use as guidance to attach each tooth in correctly at occlusion (Veeraiyan *et al.*, 2003).

2.4 Fabrication technique of removable complete denture

There are two type of removable complete denture fabrication technique known as conventional fabrication technique and advanced fabrication technique.

2.4.1 Conventional removable complete denture fabrication technique

Universities and private sectors have invested in carrying out research on denture fabrication technique. The technique divided into conventional technique and advance manufacturing technique. Intended, the method to forming denture base can see as the difference of denture fabrication technique. Nevertheless, the same procedures to each fabrication technique are used from earlier step until denture model process step which produced in dental lab. The denture process in conventional technique mostly involves first marking an impression technique on a patient's mouth by a dentist. Then the impression is sending to the dental laboratory for fabrication a denture. At the laboratory, a dental technician cast a model of the mouth using impression from the dentist, making the cast model with composition called stone powder (Kamali, 2007).

After completing all the necessary steps, the dental technologist will use an articulator to align a set of denture teeth on the stone model in alignment and in the proper position. Then the denture teeth will be secured by hand to the model of the mouth using a wax composition to make a trial denture for the patient. The trial denture will then be removed from the stone cast and sent to the dentist where they were tested to the patient edentulous. After that, a permanent plastic or polymer composition will be used as a substitute for the wax in the trial denture (Kamali, 2007). The time was requires to make a denture is usually a month. However, if there are problems that cause the patient discomfort, the denture process may reach up to six months (Yasuhiko *et al.*, 2005). Referring DENTSPLY Prostesthic Trubyte article, the conventional denture process need many laboratories steps and costumer visit procedures as shown in Figure 2.3. The details of laboratory steps were simplified in process flow as shown in Figure 2.4.

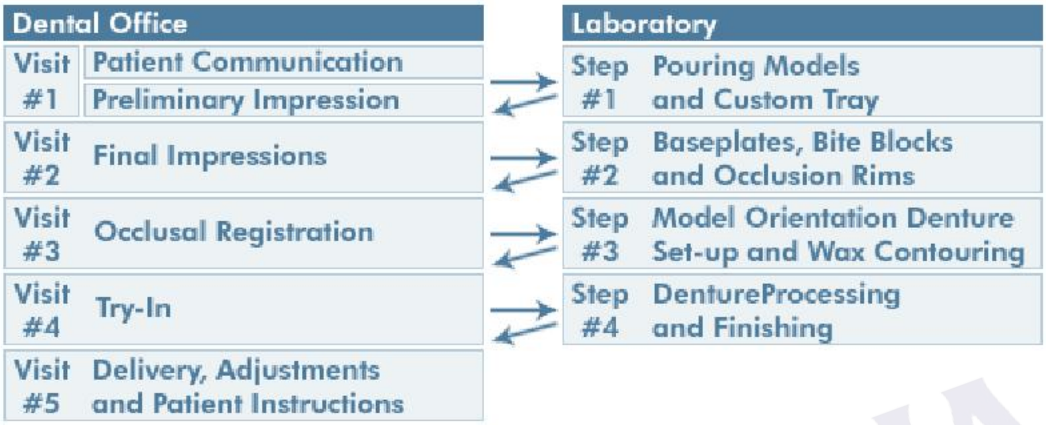


Figure 2.3: Conventional denture fabrication procedure (Deadwood, 2008)

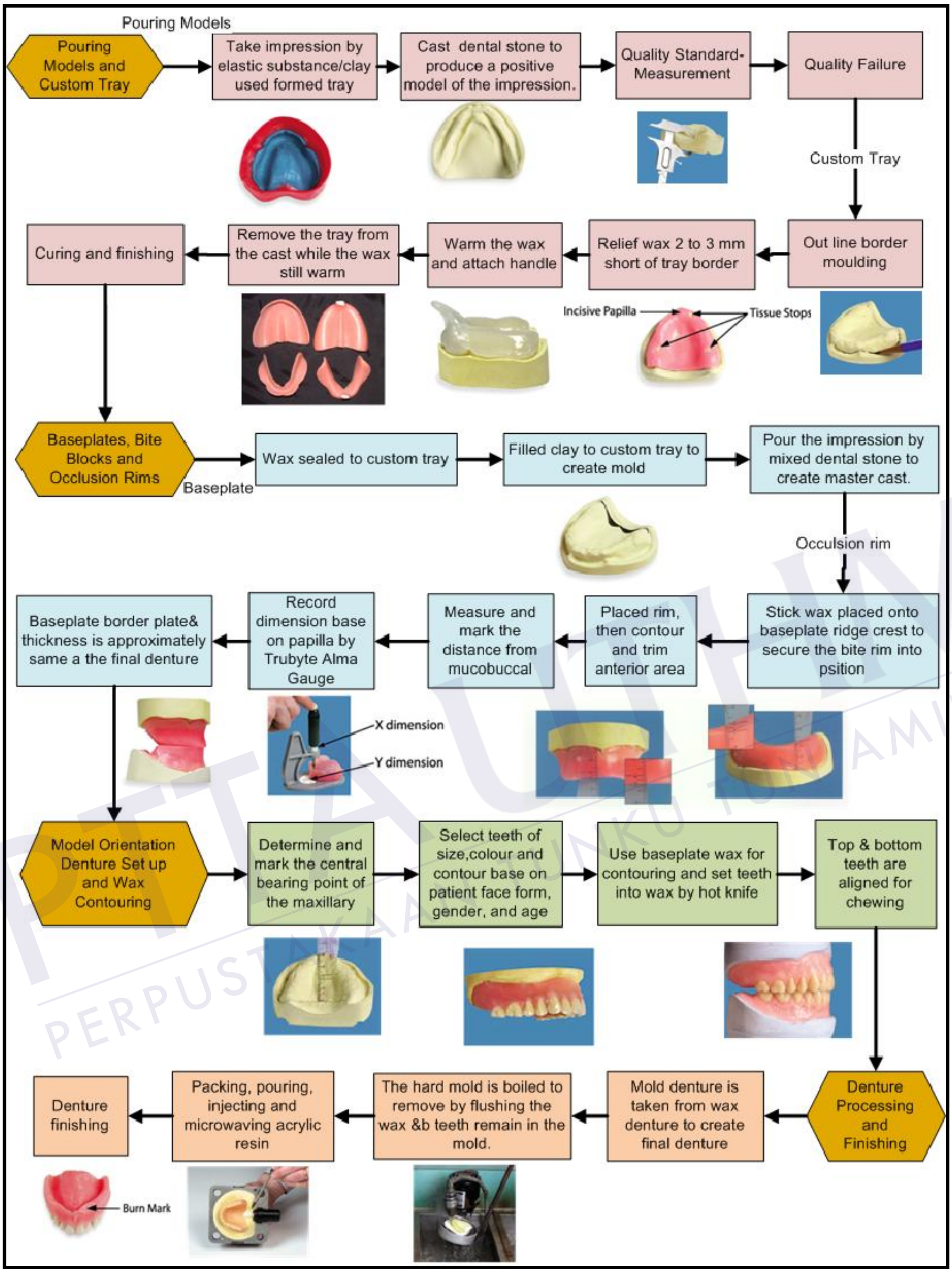


Figure 2.4: The details laboratory steps of removable complete denture in conventional technique (Deadwood, 2008)

2.4.1.1 Compression flask technique

The compression flask technique is a type of conventional denture fabrication technique in which two sections of the flask are separated after the wax is removed from the flask. Then the cavities within the stone composition are formed with the prosthetic teeth held in the position hardened stone. Next, the cavity space has been packed with an acrylic resin composition from the dough form in between of two sections of the flask. Then, the flask has been positioned within a press to squeeze out all the excess acrylic resin compositions (Kamali, 2007).

Previous research found that the compression flask techniques was constituted to conventional flask closure and Rafael and Saide (RS) flask closure system as shown in Figure 2.5 and Figure 2.6 which the RS system had a smaller base distortion compares to conventional flask closure (Rafael *et al.*, 2004). Then, the dimensional change more uniform when the denture are submitted to the 6 hour post-pressing time in RS flask closure method which these factors may reduce the magnitude of tooth movement (Wagner *et al.*, 2009).

Figure 2.5: Conventional denture flask (Handler, 2009)

Figure 2.6: Rafael and Saide (RS) flask Closure (Rafael *et al.*, 2004)

2.4.1.2 Injection moulding technique

An injector and fiber reinforced plastic (FRP) denture flask has been developed for injection moulding and the fit of the denture base constructed with this injection moulding system has evaluated. The function is to pressure the dough of the polymer-monomer mixture in the mould space. The curing technique normally used microwave heat (Kimura *et al.*, 1990). About 16% are using newer techniques such as injection moulding and microwave processing technique in addition to the conventional processing technique (Kimura *et al.*, 1991). Figure 2.7 shows the injection moulding technique for denture fabrication. The advantage of this method is the constant injection pressure compensates for the gradual shrinkage of the acrylic resin as the denture base is cured under heat and pressure. It was resulting in denture bases that fit with a smaller degree of error (Melton, 2000). However, they were no appreciable differences in the laboratory working time and procedure between the injection and compression moulding techniques. The process step just only changed from compression the denture base into plaster moulded to injection the denture base into the plaster mould.

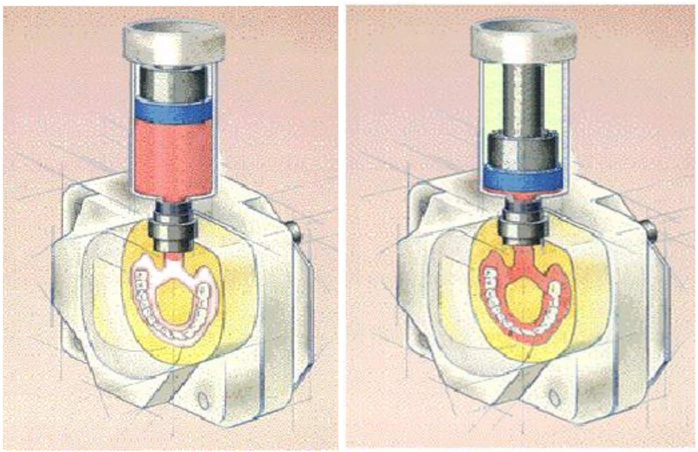


Figure 2.7: Injection moulding technique (Apex, 2011)

2.4.2 Advanced technique of denture fabrication

A study from China presented a new method for fabricating the removable complete denture by computer-aided design and Rapid Prototyping (CAD& RP) technology. The special CAD software has been developed for the 3D integrated design process of denture. They were including to automatic setting up artificial teeth, semiautomatic designing aesthetic and individualized artificial gingival and base plate are automatic constructing individualized denture. Then 3DP technology was used to make the individualized physical flasks. Following this method, the complex process of traditional handicraft has cut down to relieve the workload and improve the restoration's accuracy (Yuchun Sun *et al.*, 2009).

Another advance technique is Digital Denture Manufacturing (DDM) which it is a combination of digital imaging, CAD/CAM and RP. DDM is capable of making complex, customer specific products immediately, and eliminates time-consuming intermediate steps such as manufacture of the moulds (Chang and Chiang, 2002;Chang and Chiang, 2003) . Another of that a device for scanning denture image and reconstructing 3D digital information of teeth models by Abrasive Computer Tomography (ACT) was established. Then the orthodontic denture will be produced by Rapid Prototyping (RP) or Computer Numerical Control (CNC) machining methods based on the digital information (Chang *et al.*, 2006).

2.5 Rapid prototyping, rapid tooling and rapid manufacturing technologies

Countries around the world continue to adopt RP technology. Figure 2.8 shows the systems was sold and installed by country in 2002 (Wohlers, 2003). RP technology allows the production not only models and prototypes for visualization purposes, but also functional parts (Rosochowski and Matuszak, 2000) . The terms of rapid tooling and rapid manufacturing are subordinate to that of rapid prototyping. They were also related to special uses and application areas of rapid prototyping technology which it is a systematically and really technique (Willis *et al.*, 2007).

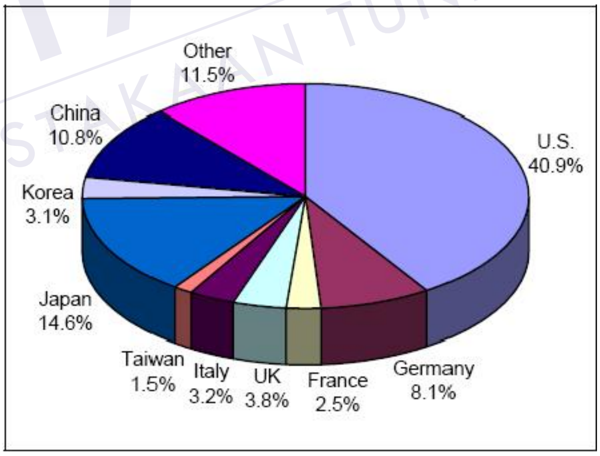


Figure 2.8: RP technology adopted around the world in 2002 (Wohlers, 2003)

2.6 Rapid prototyping basic principle

Basically, the rapid prototyping (RP) refers to the physical modelling of a design using digitally driven, additive processes. RP systems quickly produce models and prototype parts from 3D Computer Aided Design (CAD) data, Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) scans, and data from 3D digitizing systems as shown in Figure 2.9 (Rosochowski and Matuszak, 2000).

The RP systems join liquid, powder, or sheet materials to form physical objects. Through Layer by layer technique, RP machines process plastic, paper, ceramic, metal, and composites from thin, horizontal cross sections of a computer model.

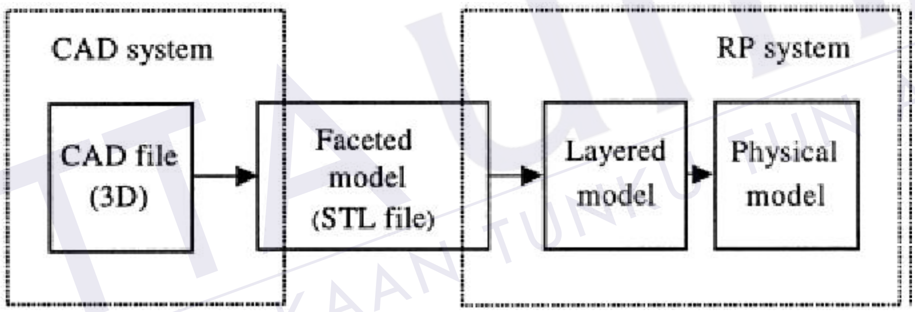


Figure 2.9: Rapid prototyping basic principle (Rosochowski and Matuszak, 2000)

2.6.1 Rapid prototyping process chain

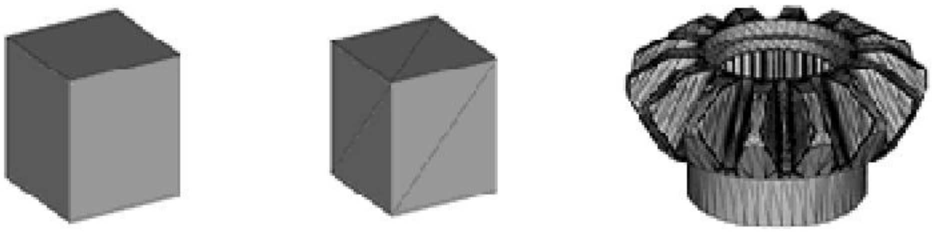
There were 5 basic step of layer manufacturing process in rapid prototyping technique:

2.6.1.1 CAD model of the design creation

Several Computer Aided Design (CAD) software package may use in 3D model design such as Autocad, ProEngineer, SolidWork, Unigraphic and other things. Besides being able to generate 2D and 3D drawings, the CAD software is also can import another external solid and surface data file such as STL, IGES, STEP and so on (Sun *et al.*, 2004). The external model as 3D surface from scanned devise such as 3D scanner (Willis *et al.*, 2007) or computed tomography (CT) scan 9 (Caloss *et al.*, 2007).

2.6.1.2 CAD model to STL format conversion

Various CAD packages use a number of different algorithms to represent solid objects. Besides that the Standard Tessellation Language (STL) is a file format native to the stereolithography CAD software created by 3D Systems has been adopted as the standard of the rapid prototyping industry to establish the consistency (Etomite, 2007). This format represents a 3D surface as an assembly of planar triangles. The file contains the coordinates of the vertices and the direction of the outward normal of each triangle. Because STL files use planar elements, they cannot represent curved surfaces exactly. By increasing the number of triangles, the approximate can be improved. Figure 2.10 shows the STL format approximates the surfaces of a solid, surface or scanned model with triangles as shown in Figure 2.10 (Eden, 2009).



(a) (b) (c)

Figure 2.10: (a) A simple model, such as the box. (b) The box surfaces can be approximated with twelve triangles, two on each side. (c) More complex the surface, the more triangles produced (Eden, 2009)

2.6.1.3 Slice the STL file into thin cross sectional layers

The pre-processing software slices the STL model into a number of layers in range 0.01 mm to 0.7 mm of thickness for rapid prototyping process. However, it has depended on the build technique. The program can be generated an secondary structure to support the model during the build. The slicing of large STL files could be generated the segments by laser or nozzle (Koc *et al.*, 2000).

2.6.1.4 Layer construction

The next step is the actual construction of the part. By using rapid prototyping machine, the construction part builds one layer at a time from polymers, paper, or powdered metal. Most machines are fairly autonomous, needing little human intervention (Palm, 2002).

2.6.1.5 Cleaning or post processing

The final step is post-processing. This involves removing the prototype from the machine and detaching any supports. It essentially consists of part removal and cleaning and curing and finishing because some photosensitive materials need to be fully cured before use. Prototypes may also require minor cleaning and surface treatment. There will improve its appearance and durability. This step generally involves manual operations where an operator does the post processing with extreme care. Otherwise, the part may be damaged, and it needs to be prototyped again (Kai and Fai, 2003).

2.7 Rapid manufacturing

Rapid Manufacturing (RM) defined as the producing of end use products by using additive manufacturing techniques (solid imaging) (Rudgley, 2001). Another definition is the direct production of finished goods from a rapid prototyping (RP) device (Wohlers, 2003). The technique uses additive processes to deliver finished goods directly from digital data, which eliminates all tooling.

In dental technology, the application of Rapid Manufacturing (RM) in manufacture real functional parts present the dental framework for implant are used Selective Laser Sintering (SLS) and Selective Laser Melting (SLM) as shown in Figure 2.11 (Kruth *et al.*, 2003). Therefore, the layer-wise material addition techniques that allow generating complex 3D parts by selectively consolidating successive layers of powder material on top of each other, using thermal energy supplied by a focused and computer-controlled laser beam (McAlea *et al.*, 1997;Gideon *et al.*, 2003;Over *et al.*, 2002). The processes have gained a wide acceptance as Rapid Prototyping (RP) techniques. Recently, a shift to Rapid Manufacturing (RM) has come up because of technical improvements of layer manufacturing processes (Gideon *et al.*, 2003;Kruth *et al.*, 2003;Kruth *et al.*, 2005). The technologies have been used in Rapid manufacturing shown in Table 2.1.

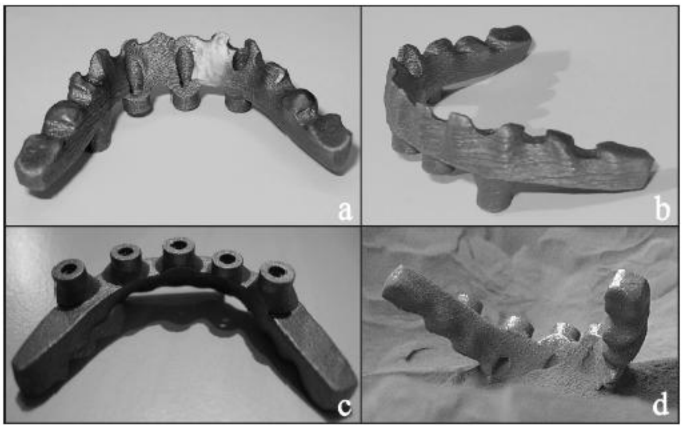


Figure 2.11: Produced frameworks by SLS/SLM from stainless steel (a, b) and from Ti6Al4V (c, d). Figure d shows the framework emerging from the powder (Kruth *et al.*, 2005)

Table 2.1: Technology Being Used for Rapid Manufacturing (Kai and Fai, 2003)

Plastic parts	Metal parts	Ceramic parts
*Selective Laser Sintering (SLS) Related process; -M3 (Concept laser GmbH) -RP3 (Speed part AB)	*Selective Laser Sintering (SLS) Related process; -Selective Laser Metling (SLM) -Electron Beam Metling (EBM) -Arcam AB	*Three-dimennsional Printing (3DP) *Selective Laser Sintering (SLS)
*Fused Deposition Modelling (FDM)	*Laser powder forming includes; -Optomec LENS (TM) -POM-Group DMD (TM) -Trumpf's Direct Laser Forming (DFL) *Three-dimennsional Printing (3DP)	*Fused Deposition Modelling (FDM)
*Stereolithography (SLA) Related process; -jetted photopolymer -spatial light modulator based exposure technologies *MultiJet Modelling (MDM)	*Sprayed metal includes; -Sprayform (Ford Global Technologies) -Rapid Solidification process	*Robocasting (TM) Related process; -Optoform (3D System)

2.8 Rapid tooling (RT)

Rapid tooling describes those applications that are aimed at making tools and moulds for the production of prototypes and pre-series by using the same processes as those used in rapid prototyping (RP). Another of that Rapid tooling is a progression from rapid prototyping which it is the ability to build prototype tools in contrast to prototype products directly from the CAD model resulting in compressed time to market solutions (King and Tansey, 2002). Figure 2.12 shows the comparison between rapid tooling and rapid prototyping in direct tooling.

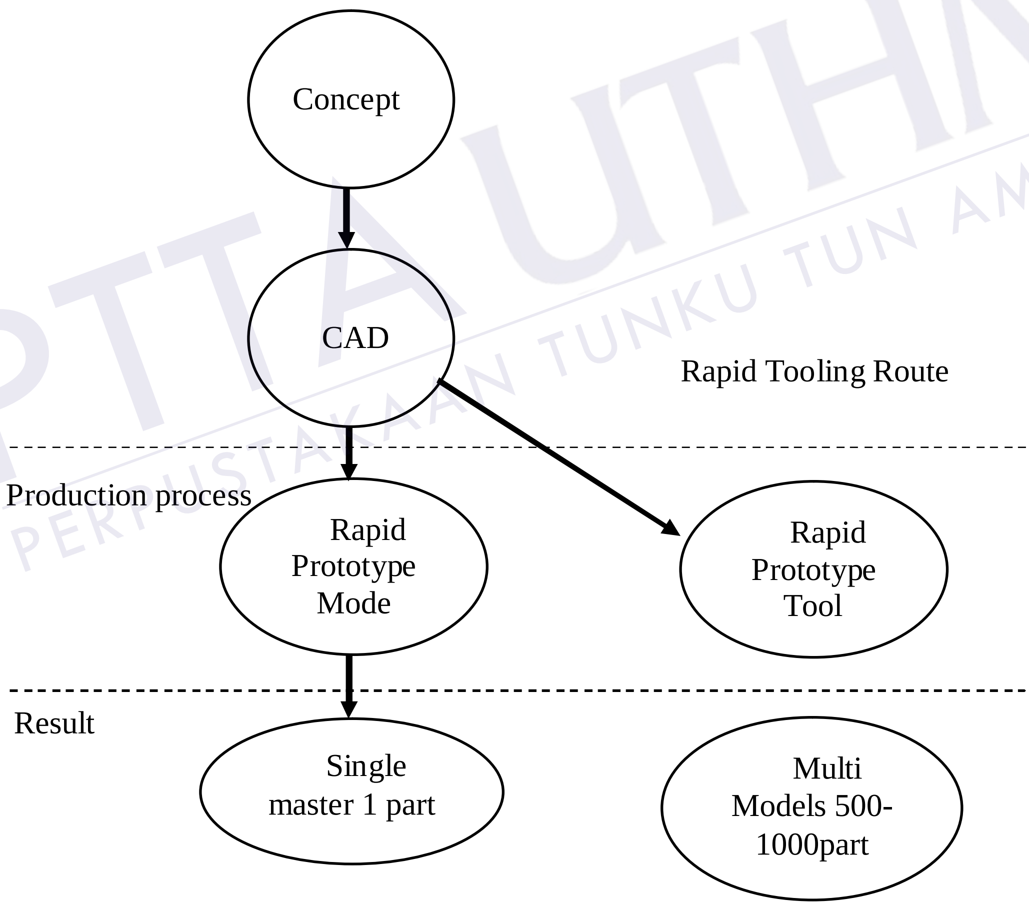


Figure 2.12: Comparison of rapid prototyping to rapid tooling (King and Tansey, 2002)

2.8.1 Rapid tooling (RT) classification

Figure 2.13 shows a classification of RT techniques such as pattern for casting, indirect tooling and direct tooling. In patterns for casting, it concentrating on producing patterns for the foundry industry. While for indirect tooling, it was used patterns for soft and hard tooling. Whereas for direct tooling, it was manufacture the tools directly on RP machines (Rosochowski and Matuszak, 2000;Nagahanumaiah *et al.*, 2008).

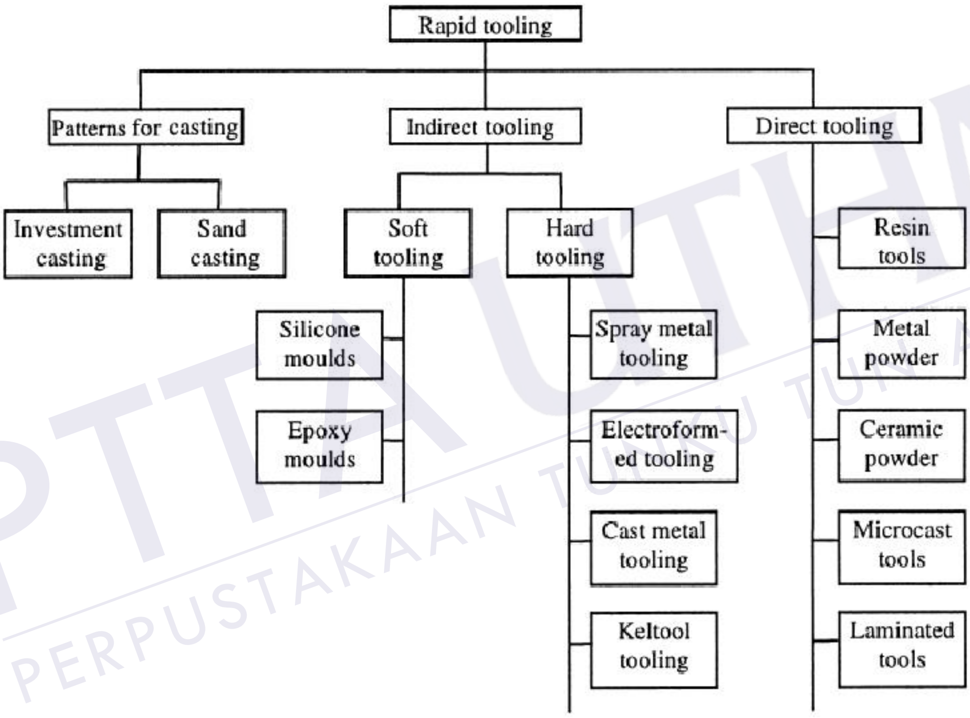


Figure 2.13: Classification of RT (Rosochowski and Matuszak, 2000)

Besides that, more than 25 rapid tooling processes are obtainable, and also has been classified based on their expected mould life means the number of that can be produced in the mould, as soft, bridge and hard tooling. Therefore the most important RT processes useful for developing injection moulds are listed in Table 2.2, which it was indicating the related RP process and their classification. The soft and bridge tooling methods can produce either non-metallic or softer metal (compared to conventional tool steels) moulds and usually cannot withstand the pressures and temperatures involved in conventional injection moulding. Then the hard tooling methods facilitate fabricating metal tooling that can be used in injection moulding machines, and result in improved quality and larger quantity of parts compared to soft and bridge tooling (Nagahanumaiah *et al.*, 2008).

Table 2.2: Important rapid tooling processes and their parent RP processes (Nagahanumaiah *et al.*, 2008)

No	Rapid Tooling Process	Patent RP process	Type of Rapid Tooling				
			Direct	Indirect	Soft	Bridge	Hard
1	SLA Direct-AIM	SLA	X		X		
2	SL EP 250 moulds	SLA		X		X	
3	SLS rapid steel	SLS	X				X
4	Direct metal laser sintering	DMLS/SLS	X				X
5	Direct shell production casting	3DP		X			X
6	Prometal RT300	3DP	X			X	
7	Metal laminated tooling	LOM	X				X
8	Multi-metal layer tooling	SDM					X
9	SDM mould	SDM		X	X		
10	Investment cast mould	SLA,FDM		X		X	X
11	3D Keltool	SLA, Keltool		X			X
12	Spray metal tooling	SLA, SLS, m/c pattern		X		X	
13	Vacuum Casting	SLA, SLS, m/c pattern		X	X		
14	RP pattern base powder sintering	SLA, SLS		X			

2.9 Development of rapid prototyping technology

On the basis of the fundamental physical processes, in a little more than 15 years after the presentation of the first prototype, more than 30 industrially useable prototypes for the direct computer supported manufacturing of physical models have

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