COMPUTER APPLICATION OF RAPID MACHINING TECHNIQUES FOR THE CREATION OF RAPID PROTOYPING

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ABSTRACT

Rapid machining is a new technique recently made possible by the advances in control system technology. It is a technique that has been overlooked by many industries as means of producing rapid prototypes. The rapid prototyping systems work with different techniques using waxes paper and metal powder. The fused deposition modelling (FDM) system using wax was developed in this work. The FDM machine builds the part by extruding semi-molten wax through a heated nozzle in a prescribed pattern onto a platform. The present paper describes the basic system design, and the method of wax deposition. The extrusion jet is mounted on a X-Y-Z table which is controlled by a computer system. Automated control of the plunger mechanism and the platform position allow for accurate parts to be produced. Single layers of wax are built up one on top of the other to produce the final part shapes. The characteristics of wax were also analysed in order to optimise the model production process. These included wax phase change temperature.

INTRODUCTION

Rapid Prototyping technology is group of processes that enable the direct physical realization of 3D computer models [1]. Rapid Prototyping (RP) systems have been existent since quality and specific design criteria have come to the fore of the manufacturing process. Today's commercially available rapid prototyping systems work with different techniques using paper, polymers and waxes [2]. RP is a generic name for a range of new technologies capable of producing physical models directly from CAD data in a very short timescale [3].

There are many kinds of rapid prototyping now available within the manufacturing industry. Prototyping has become a necessary and means to test and physically examine design, which are otherwise viewed with difficulty from either two dimension or three dimension schematic formats. These three dimensional RP machines allow designers to quickly create tangible prototypes of their designs, rather than just two dimensional pictures. Prototypes can be used to demonstrate the concept, design ideas and the company's capability in producing it. There are number RP technologies on the market, most of which work under the same fundamental principals. CAD data for the designed part, in a specific file format (usually STL nowadays), is processed and oriented in an optimal build position. The data is then sent to the RM machine where it is numerically sliced into thin layers. The RP machine then fabricates each two-dimensional cross section and bond it to the previous layer. A complete prototype is thereby built by stacking layer upon layer until the prototype is completed. There are two main types of RM, subtractive and additive. Subtractive techniques involve the removal of material from a block to produce the prototype. The CAD data is converted onto CNC data in order to control the CNC equipment for automated cutting of the block. Generally softer materials are machined to produce the prototype so that high cutting speeds can be used (for example polystyrene or plastic). Similarly, a prototype aluminium injection mould tool may be produced for evaluation, with this technique, whereas conventional prototyping methods would produce a steel die. Most modern RP techniques are however additive.

Rapid Prototyping building up a 3D object [4], developed by Strategy's Inc. Fused Deposition Modeling, this method is most easily explained by understanding its name. Deposition entails that something will be deposited and then fusion will bond that which is deposited to the rest of the model [5]. FDM is the second most widely used rapid prototyping, after sterolithography. The wax is melt and an extrusion from nozzle. The nozzle is heated to melt the wax and has a mechanics which allows the flow of the melted wax to be turned on and off. The nozzle is mounted to and off. The nozzle is mounted to a mechanical stage which can be moved in both horizontal and vertical direction. The concept is that a material is fed through a heating element, which heats it to a semi-molten state [6].

The FDM technology allows a variety of modelling materials and colours for model building [7]. Available materials are wax, plastic, paper, ABS (acrylonitrile butadiene styrene), adhesive material, all the materials are non-toxic and can be in different colours [8].

EXPERIMENTAL SET- UP

System design

The system contains two main sub-systems, the X-Y table and the deposition unit. The system is shown in figure 1. Two servomotors connected via linear guide and lead screws control the x-y movements of the deposition unit. Anther servomotor controls the amount of material deposited from deposition unit.

The overall control of the system was implemented by writing sequential control algorithms to manipulate the movements of each unit in synchronisation to allow deposition to occur correctly. The deposition chamber consists of an aluminium nozzle ended cylinder to deposit droplets of wax. The material chosen for the deposition chamber was important to allow conductance from the heating element to occur efficiently and easily so that the wax was fully molten and under tight temperature control.

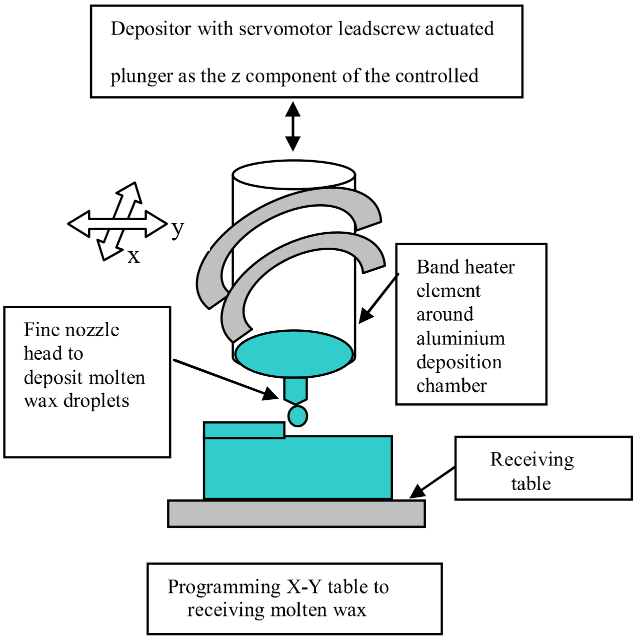


Figure 1 Schematic of the fused deposition modelling system developed

The experimental equipment used in the current research is shown in figure 2. The apparatus consists of a personal computer, PC-23 indexer, KS-driver, deposition chamber, temperature controller, and thermocouple and pressure gage. A personal computer was used to control the system by sending commands and receiving responses from the PC-23 indexer. The indexer in turn communicates with the KS-drive for controlling the a.c. brushless servomotors. The system was used for additive prototyping and to measure the viscosity of the wax material used in this work.

FDM OPERATION

Fused Deposition Modelling is a Rapid Prototyping (RP) technique. Its basic principle is to build 3D physical models, layer by layer, directly driven by the computer system. The material is heated within a heating chamber and extruded through the nozzle, which moves in the X and Y direction [9].

The computer controls the motion and the material deposition out of the nozzle. The droplets fall onto a platform and stack up a 3D object layer by layer, see figure 2.

The FDM technology builds models, layer by layer directly from three-dimensional digital models with appropriate selection of temperature and pressure repeatable dimension of the droplet can be obtained the temperature was 84 ºC, see figure 3 (a). With increased temperature at 88 ºC in this case, surface finish dimensional accuracy determinate, see figure 3 (b). The viscosity of the wax was also measured, by using the depositor as a capillary viscometer. Deposition temperatures in the range of 75 to 90°C and pressures in the range of 34,487 to 172,370 Pa (5 to 25 psi) were investigated. The deposition plate was placed 40 mm below the 20 mm long nozzle, which had an internal diameter of 1 mm. This capillary geometry allowed the depositor to be used as a capillary viscometer to measure the viscosity of the wax.

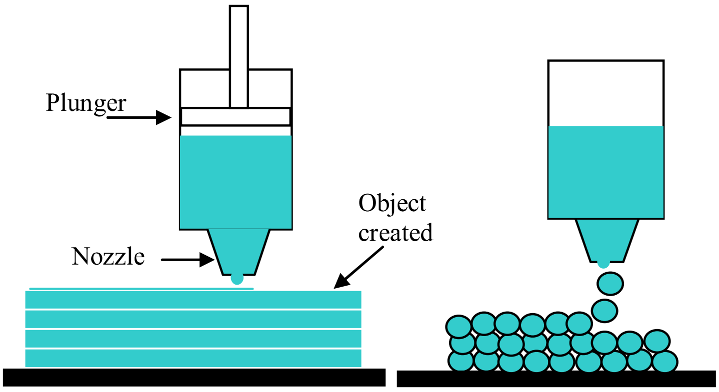
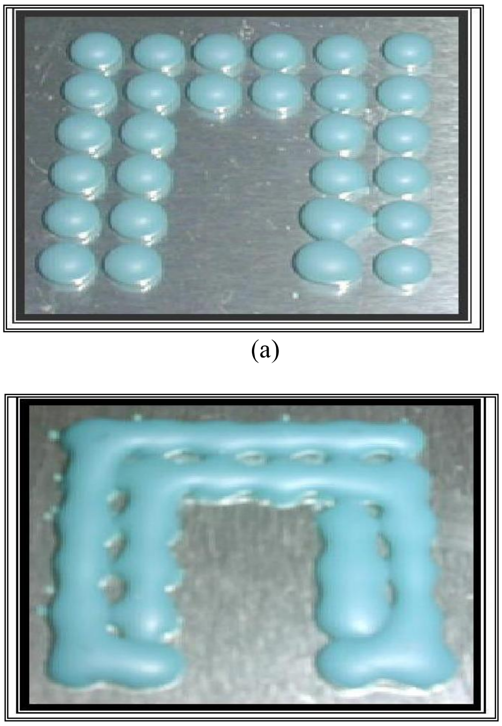


Figure 2 Schematic illustration of the fdm process


(a)

(b)

Figure 3 (a) , (b) Schematic illustration of built of pattern for various deposition temperatures

The equation used for the viscosity measurement is as follows:

$$\eta = \frac{\Delta P \ \pi \ r^4}{8 \ L \phi} \qquad (1)$$

where ϕ is the flow rate of liquid out of nozzle [m² / s], r is the radius of nozzle [m], Δp is the pressure difference over length of nozzle [kg / s^2 m], L is the length of nozzle [m], and ηis the viscosity [kg/ms].

With appropriate selection of temperature and pressure repeatable dimensions of the droplet can be obtained. Too high a temperature is detrimental to surface finish and dimensional accuracy.

RESULTS AND DISCUSSION

Effect of deposition height

Initial tests were performed with the nozzle at different heights. It was found that for deposition heights much below or above 40 mm that too wide a diameter droplet resulted. It is thought that for deposition distances below 40 mm the drop was too fluid when it hit the deposition plate and that for distance above 40 mm there was too much droplet momentum. The distance between the nozzle and receiving plate was therefore set at 40 mm in all experiments. In the deposition experiments, the droplets were deposited onto a receiving plate which was placed 40 mm below the nozzle to allow the droplets to have an adequate time to be partially solidified.

Wax phase change analysis

Figure 4. Shows the temperature against time of the investment wax for this experiment. Above 58ºC the wax was liquid and below 56 ºC completely solid. This information allowed appropriate setting of the temperature parameters to be investigated for the rest of the experiments. Initial deposition tests for temperatures in the range of 58 to 70 ºC however prove very difficult to process. It is believed that this was due to the larger temperature fluctuations that would be expected to occur in the larger test vessel of the deposition chamber.

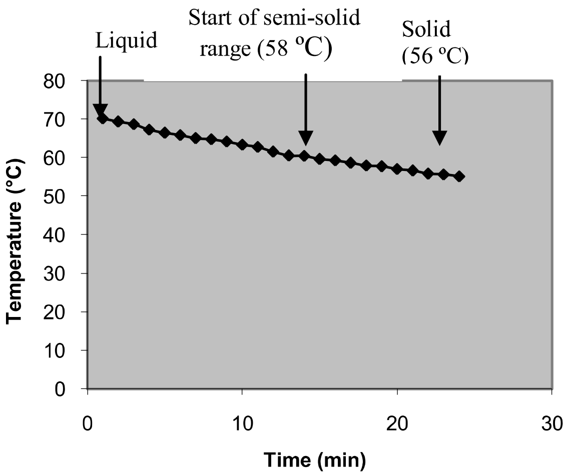


Figure 4 Graph of temperature versus time for the cooling wax

Droplet size analysis

A number of experiments were carried out to investigate the performance of the unit by using material of the wax the experiments were performed under the low pressure. This is typical occurrence which is observed in all experiments for wax droplet the droplets can be observed to be very round, uniform and evenly spaced, also as shown the droplets are aligned into a straight line. This implies that the droplets are all moving in the x, y direction at the same speed, and different temperature which is one of the basic requirements for a good droplet deposition. The figure 5 shows the variation of droplet dimensions with regard to the height of droplet at various temperatures by using the motors (X-Y-Z) movement.

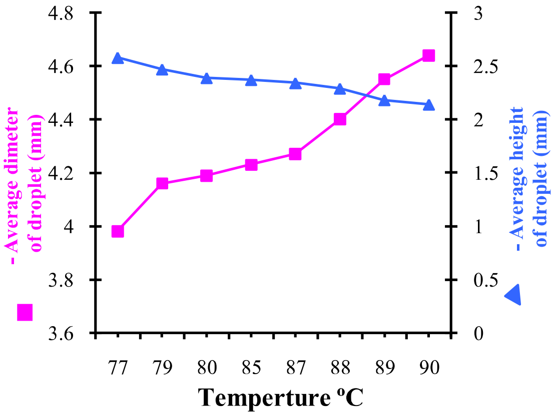


Figure 5 Illustrated diameter of droplet and height for various temperatures

In this experiment to measure diameter and height for each temperature. Droplet sizes was obtained from a nozzle was measured by using digital vernier scale. A large droplet size was obtained with increased the temperature. Thereby increases a temperature influences upon increased the diameter of droplet and increases temperature the heights of droplet decreases.

In results are presented of measured diameters and heights of droplets against various temperatures. The diameter of droplets at a temperature of 77 ºC to 90 ºC was increased when the temperature was increased. Therefore when the temperature of liquid wax increases, the diameter of droplets increases in the stage as shown in figure 5. In results, at temperatures of 77 to 90 ºC, the diameter of droplet increased. At this stage, it was possible to derive the effect of temperature on the diameter of droplets. Similarly, the same experiments were carried out for the height of droplet at temperature of 77 to 90 ºC it was found that temperature decreased on the height of the droplets as shown in figure 5.

Other measurements were carried out to calculate the standard deviation and confidence interval of diameters and heights of the droplets of impeller shape. The standard deviation was calculated for different shape and the temperature was 83 ºC. The standard deviation was calculated from the following formula.

$$S = \sqrt{\frac{\Sigma\left(x-\bar{x}\right)^{2}}{n-1}} \qquad (2)$$

where S is standard deviation, x is the value of each datum,

$\bar{x}$ is the mean value, n is the number of data. The confidence interval was carried out of length and thickness and height of impeller shape it was calculated data from table 1. To measured the length and thickness and height of impeller shape using digital vernier scale and recorded the data in table 1.

Table 1. Measurements of the length, thickness and height and the number of drops

Length (mm)	Thickness (mm)	Height (mm)	Number of drops
64.39	8.27	25.14	8
64.83	8.22	24.84	8
64.73	8.75	26.93	8
65.40	8.58	27.25	9
64.55	8.56	24.31	7
65.39	8.75	25.75	8
65.16	8.01	23.44	7

To calculated the confidence interval was used the formula is given.

$$\mu = \bar{x} \pm t_{n-1}\frac{s}{\sqrt{n}} \qquad (3)$$

By using a table t-distribution, a 95% confidence interval was calculated. To calculate the mean and standard deviation of data. From the results obtained the different values a round the mean of data, if the values is large, it is the theoretically possible to choose confidence intervals which are between the range of values. After calculated the data it was obtained different values of standard deviation and confidence interval was presented in table 2.

Table 2. Standard deviation and confidence interval of the length and thickness and height of shapes at a temperature of 83 ºC

Parameters	Length (mm)	Thickness (mm)	Height (mm)
Average	64.92	8.35	25.38
Standard deviation	0.4022	0.4486	1.37198
Confidence interval	± 0.0095	± 0.01063	± 0.0325

The same experiment was carried out to calculated the standard deviation and confidence interval of impeller of shape by using airflow to obtained different shapes and different values.

The standard deviation of the length and thickness and height were calculated using the same formula for the standard deviation and confidence interval. The data was presented in table 3.

Table 3. Measurements of the length, thickness and height and the number of drops by using airflow.

Length (mm)	Thickness (mm)	Height (mm)	Number of drops
64.22	8.73	27.14	8
64.42	7.82	26.44	8
64.01	8.88	26.94	8
64.30	8.23	26.93	8
63.97	8.37	26.67	8

After calculated the data it was obtained different values of standard deviation and confidence interval was presented in table 4.

Table 4. Standard deviation and confidence interval of the length and thickness and height of shapes at a temperature of 83 ºC using airflow

Parameters	Length (mm)	Thickness (mm)	Height (mm)
Average	64.18	8.20	26.98
Standard deviation	0.19138	0.37326	0.56883
Confidence interval	± 0.00536	± 0.01046	± 0.01595

Viscosity Measurement At Different Temperatures

In another experiment was carried out to measure the viscosity against temperature with constant pressures as shown in figure 6 In the first curve when the pressure was constant at 5 psi (34,473 Pa) and temperature 75 ºC, the value of viscosity was 3.89 Pa.s. At the temperature of 78 ºC it was observed that the value of viscosity decreased to 1.41 Pa.s. Again by increasing the temperature to 80 ºC, observed that the value of viscosity decreased with increasing temperature of wax. When the pressure was constant at 7 psi (48263.29 Pa) and the temperature was 75 ºC the value of viscosity is 1.66 Pa.s, the value of viscosity decreased gradually as temperature increased and so on. Evident in figure 6 the values of the viscosity between 80 to 90 °C the viscosity of wax was observed to decrease markedly with increasing the temperature till a certain limit and then show trivial or no change was recorded with increases in temperature was increased. It is concluded the temperature effect on the viscosity of wax. It was observed in all experiments that both the pressure and temperature affects the viscosity of the wax. When the pressure increases the viscosity decreases and the same with temperature. The decrease in fluid viscosity indicates that the large effect of pressure on the wax and that shear viscosity decreases with a rise of temperature. Overall, fluid viscosity decreases with pressure and temperature.

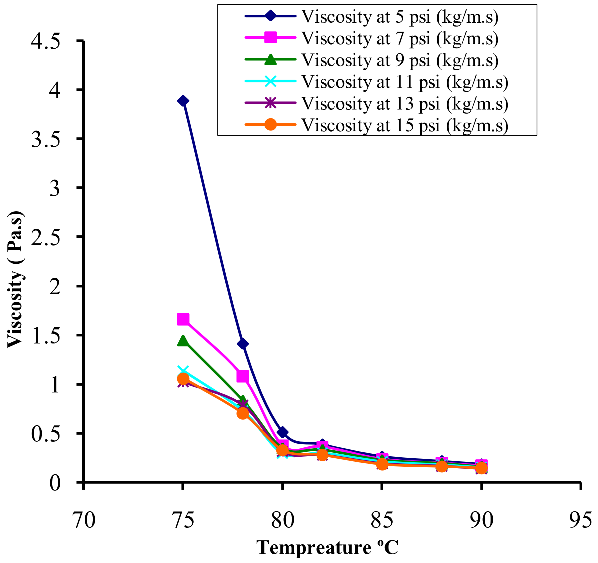


Figure 6 Results of viscosity versus temperature measurements

Viscosity Measurement At Different Pressures

The experiment was carried out to measure the viscosity against the pressure with different temperature. The result shows relationship between viscosity and pressure for a given wax melt at the required temperature. It was necessary to a make correction to the analysis in order to obtain the correct value of viscosity. All viscosity measurement was conducted at (75 to 90 °C) with pressure ranging from 5 psi to 15 psi (34473.78 Pa up to 103,421.3 Pa). When the pressure was increased the value of viscosity was decreased markedly while the temperature was constant at 75 °C the temperature was constant 78 °C it was observed the value of viscosity was 1.41 Pa.s at a pressure of 34473.78 Pa. Compared with the value of viscosity when the temperature was 75 °C the value of viscosity is 3.89 Pa.s at a pressure of 34473.78 Pa. It was conceded that the of viscosity decreased with as temperature increased and the pressure. When a temperature was 80 °C and the pressure was 1 psi (6894.75 Pa), it was observed the value of viscosity was decreased compared with first and second experiment, as temperature was constant at 80 °C and the pressure was increased in that stage observed the value of viscosity at a pressure range from 41368.54 Pa to 103,421.3 Pa no change in the value of viscosity markedly. And the same at temperature range between 82 to 90 °C and the pressure range from 6 psi to 15 psi (41368.54 Pa to103,421.3 Pa) the value of viscosity was constant as shown in figure 7.

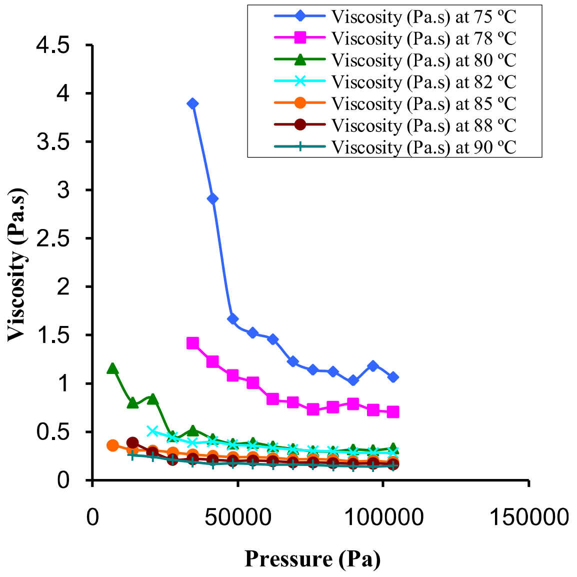


Figure 7 Illustrated the viscosity against the different pressure

Produce 3-D Objects

The FDM process to deposits material to build 3-D objects. The droplets were observed to be very round, uniform, and evenly spaced. In addiction the droplets are aligned in a straight line. This implies that the droplets are all moving in x-y direction at the same speed, which is one of the basic requirements for good droplet deposition system. In the deposition experiments, the droplets were deposited onto a receiving plate which was placed 40mm below the nozzle to allow the droplets to have an adequate length of flying time to be partially solidified. The droplets were fully solidified to from models as shown in figure 8.

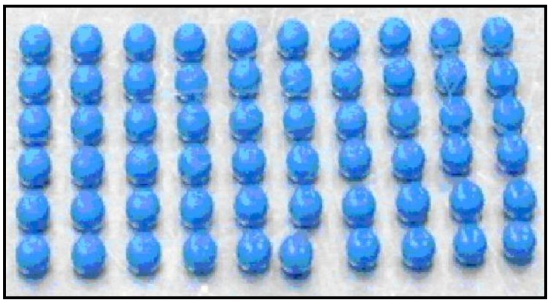


Figure 8 Illustrated the shape was built at 85 °C

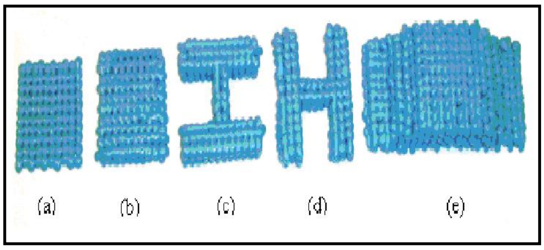


Figure 9. (a) 2-D square (30mm, 30mm, (b) two layers of (a) structure, (c) three layered I-beam structure, (33mm, 36mm long, 3 drops thick and 12 drops long), (d) H form, (e) shows 3-D stepped structure (78mm length and 26 drops, 30mm wide, 10 drops).

CONCLUSION

The rapid prototyping technology using fused deposition modelling was investigated and successfully applied in this research to produce two-dimensional and three- dimensional prototypes. The results achieved within this project shows the successful deposition of wax as a prototyping technology. The system controlled by a computer system was used to build various shapes. The demonstration of the various controls of the processes to implement even elementary models displayed the possibilities of the system. The measurement of diameters and heights of droplets against various temperatures was achieved. The diameter of droplet in the temperature range 77 ºC to 90 ºC was increased with increased the temperature. Therefore a temperature effect on the diameter of droplets of wax is evident in the result. In addition, it was found in experiments that the apparent viscosity of wax decreased when the pressure was increased. The viscosity measurements however indicated that a minimum temperature of 82 ºC should be used to obtained adequate fluid flow. A pressure above 34,487 Pa was also required in order to provide sufficient fluidity. Upper bounds of 85 ºC and 68,974 Pa were also noted from these experiments. Above these settings the wax would be too fluid and would flow from the deposition chamber uncontrollably.

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