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DEVELOPMENT OF A LOW-COST MINIATURE WATERJET MACHINE FOR MICROMACHINING APPLICATION

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Abstract (English)

The waterjet machine has found wide acceptance and applications in the industries for the past few decades. It is proven to be sufficient for many cutting problems. The present work focuses on the design of miniature waterjet machine. The design of the waterjet machine was conducted based on various stages of product development process. All necessary systematic approaches in a product design based on VDI-guideline 2221 are presented in the present work. The main approaches begin with understanding the specification of the task in developing the miniature waterjet machine. It is then followed with evaluation of the conceptual design of the machine. Finally, the development of the final design of the miniature waterjet machine is presented.

Abstrak (Bahasa Malaysia)

Penggunaan mesin jet air di dalam industri telah ditemui meluas sejak beberapa dekad yang lalu. Ia telah terbukti bersesuaian sebagai solusi terhadap pelbagai masalah pemotongan. Kajian terkini telah dilakukan dalam memberi focus kepada reka bentuk mesin jet air bersaiz mini. Kajian telah dilakukan berdasarkan pelbagai peringkat proses dalam pembangunan produk. Segala pendekatan yang sistematik telah dilakukan berdasarkan garis panduan iaitu “VDI-guideline 2221” yang telah dibentangkan sepanjang projek ini. Pendekatan utama bermula dengan memahami spesifikasi tugas dalam membangunkan mesin jet air bersaiz mini. Ia kemudian diikuti dengan penilaian konsep reka bentuk mesin. Akhirnya, pembangunan reka bentuk mesin bersaiz kecil yang terakhir telah dibentangkan.

Bab 1 Pengenalan

Nowadays waterjet cutting is one of a method that is widely used in most of industrial applications because its ability to cut material either hard or soft by using water stream. The cutting process can be done by applying a pure water to cut soft materials such as foam or by adding abrasive to the stream to cut hard materials such as metals effectively. The operating principle of this process is by forcing a large volume of water through a small hole in the cutting head. The small hole or either known as orifice is place at the upper part of nozzle to reduce the cross sectional area to achieve a high velocity of water by maintaining a constant volume travelling through the cutting head. The high velocity of water will accelerate when going out the nozzle to cut the materials.

Typically in a larger manufacture industry the stream of water produced under the pressure of 276 MPa up to 414 MPa [1]. During the cutting process the material is placed on the bed and the CNC controller is programmed. Once the process start the nozzle will move around the bed to cut the material. A typical waterjet machine consist of controller, cutting head, pump, system and machine table. The movement of cutting head is controlled by a computer. When the computer has been properly programmed, the cutting head will move around the bed of a machine as per instructed. The cutting head will move all over the area of machine's bed to get the desired cut. The cutting head of a waterjet machine allow the water to enter at the inlet and will be left through a small orifice located at the bottom part of cutting head. In the case of abrasive cutting, the high velocity exits the small orifice to create a suction effect to pull in abrasive particles in the nozzle. Most importantly the waterjet machine works with various types of high pressure pump. The high pressure pump provides designated flow rates of water at a consistent high pressure. Finally, a waterjet machine table is where the material to be cut is placed. The maximum area that the XY motion control system can move is by determine the length and the width of the machine table [1].

As the popularity of waterjet has grown, there are several reasons why waterjet has become the recent versatile and flexible machining tool. The combination of water and abrasive in material cutting allow waterjet to cut with a wide-ranging variety of material. The materials are included copper, brass, aluminium, brittle materials and flammable materials. Not only that there is no heat affected zone (HAZ) on materials because the little heat formed by the waterjet is absorbed by the water and passed into the catch tank [2]. Moreover waterjet machine is one kind of cutting process that is more environmentally friendly. Typically, the abrasive use for abrasive waterjet is garnet where garnet is a non-reactive mineral that is biologically inert [2].

Waterjet machine used in industrial application nowadays only use in larger size. The cost of producing one waterjet machine depends on the size of the bed which will indicates the cost of the waterjet machine itself. Meanwhile the cost of purchasing one whole set water jet machine may ranges from hundred thousand up to half a million. Considering to its industrial size, once the waterjet machine is being placed, it is fixed and difficult to move and consuming many space to be installed. Thus the problems mentioned are common therefore this project is carried out to develop a miniature waterjet machine for university used with expected result to minimize the size of waterjet machine and able to make the waterjet moveable. This main purpose of this study is to design a miniature waterjet machine by using product design and development concept. Furthermore, a low cost miniature waterjet machine is to be developed.

This project is related in developing a waterjet machine for the universities used that will comes in smaller size and minimum production cost. This project will focus on main components of waterjet machine which are the pump, pipe and cutting head, machine bed and CNC controller. Thus to achieve the purpose on developing miniature waterjet machine, the type of components that will be reduced in size are the pump, machine bed and CNC controller. However this product development process will be done according to VDI guidelines 2221 [3]. This product development guideline divides into four main phases that contain several work stages that have to be worked out. Therefore, at the end of these phases the design of the product will be carried out.

Bab 2 Kajian Literature

These reviews of previous research that have been made is provided related to waterjet machine system, product life cycle and product design and development guidelines. This chapter also involves a review on research studies on waterjet machine parameter that involves the parameter of waterjet components. Related literature has been studied on the types of nozzle used and high pressure water pump. This review has been well elaborated to cover the product development guideline about product design and development. A study has been made in order to help classifying the proper way to develop a product that involved product selection and cost comparison. The review is properly detailed so that the present research effort can be properly followed to add to the current body of the literature as well as to justify the scope.

In the development decisions concept it is offer the life cycle services and after sale supplies where the concept will not only cover the product specifications and the product's basic physical configuration [4]. There are five basic decisions to be made. With the help of questionnaire such as; 1) what are the target values of the product attributes?, 2) What will the product concept be?, 3) What variants of the product will be offered?, 4) What is the product architecture? And, 5) what will be the overall physical form and industrial design of the product?

A suitable representation of a product is a course of attribute such as speed, price, reliability and capacity [4]. They anticipate attributes to refer to both customer needs which can also be known as customer attributes or customer requirements and engineering characteristics or technical performance metrics or product specifications. A comprehensive discussion of the issues related with evaluating and using customer needs that provided. A conjoint analysis is a designed approach to optimally regulate the target values of these attributes by using given a representation of a product as a set of attributes. This attribute-based method is kind of limited methods to be able to represent the overall demand of products, especially those for which aesthetics and other universal product attributes are important. A journal offer a cross methodology in which attribute-based methods are complemented by the use of representative physical samples to stimulate consumer liking information. Ample of the research on setting attribute values is also target on take full advantage of customer satisfaction or market share, and does not openly consider design and production costs or overall effectiveness. In addition, the research on setting attribute values that have been done in the context of packaged goods are often assumes that random combinations of specifications are possible. While it may be possible to provide any combination of "crunchiness" and "richness" in a chocolate cookies, it is not possible to offer a random combination of "compactness" and "image quality" in a camera. Attributes are an idea of a product. Concept development also makes best of the embodiment of these attributes into some kind of technological approach where they call a core product concept. The decision of which technological approach to follow is often sustained by two more focused activities which are the concept generation and concept selection. Most of the textbooks which regard on the design and development discuss are also focus on concept generation.

The five categories of process modelling are the sequencing and planning simulations, disintegration simulations, stochastic lead time simulations, design review timing simulations, and parallelism simulations [5]

2.1 Sequencing and scheduling.

Sequencing and scheduling design tasks covered when the product development is separate from many activities with project-like theme, in that iteration and rework are commonplace. A difficulty to fine the appropriate orderings occur with the presence of iteration. Firstly, by using design structure matrix (DSM) method take on that each design task can be displayed as an information processing task to use and create information. The final information from one task will becomes the initial information for another task. The final/initial relationships may (in all likelihood) include cycles, which specify the need for iteration. The DSM formulation is represent a matrix form that includes these relationships. Tasks in the matrix may be re-organised, which helps identify repeated and acyclical tasks.

2.2 Breaking down large systems into subsystems.

The decomposition of a larger systems, an important task within product development management the large design projects should be divided into smaller fundamentals. This decision is hard, imperative, and responsive to formal analysis, and has therefore been the target of several simulations. Decomposition of large systems is beneficial either to assign the work among multiple designers or design teams, or also to suggest a disintegration of the technical object that will minimize intersecting between subsystems. Decompositions therefore help to increase speed of the design process and also help to create higher performance design outcomes.

2.3 Iteration of product development and delays.

To determine the effects of stochastic intervals on product development lead time, the effect that is possibly important to product development that are not captured in PERT/CPM models of product development is the need for iteration as well as the potential delays in product development because of line up delays. The simulations in this subsection recognize that product development projects do not occur in segregation, but instead there are several simultaneous projects that are competing for the same limited resources. The inadequate availability of resources might causes delay in the overall project that can unpleasantly affect overall project lead time.

2.4 Simulation and activities for product effectiveness.

Determining the timing of design reviews/product release, another class of simulations concerns the effectiveness of activities that are related to the design process, but are not design tasks themselves where the activities covered design reviews and product release.

2.5 Sequential scheduling in design process

Determining the amount of parallelism. A simulation is described to indicate that there are valid reasons for maintaining some amount of sequential scheduling in the design process as a method to lower the costs and reduce the size and difficulty of the organization required to support design activity.

Bab 3 Methodology

Methodology is a method that refer more than one method sometimes accompany by training, worksheet and diagramming tools. It is including documents that record all the phases of the product development such as requirement, designs, development, assembly, testing and maintenance. Methodologies also include diagramming notation for documenting the result of the project whether it is acceptable. Figure 1 shows a plan to work on development of waterjet machine according to VDI 2221 guideline.

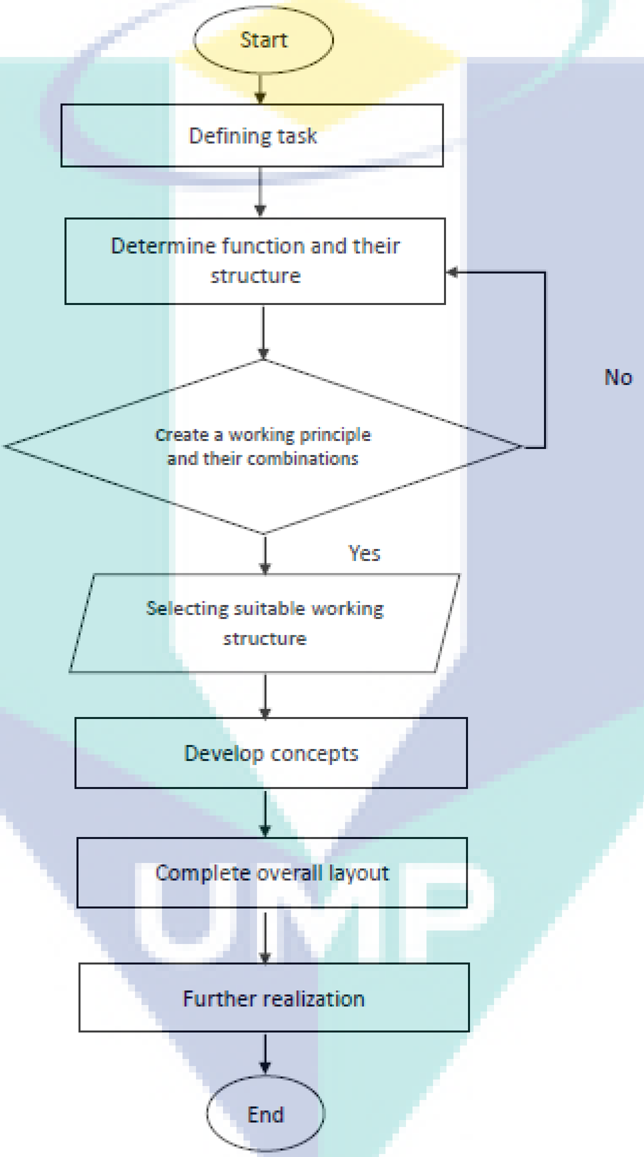

Fig. 1: Various product development stages according to Guideline VDI 2221.

Bab 4 Data & Perbincangan

Regarding to the function of waterjet machine, the machine is presented in 3D drawing by using Inventor. Therefore, all the components of waterjet machine is drawn up and all the dimensions is ensured. Figure 2 and Figure 3 show the drawings of the machine at front and isometric respectively.

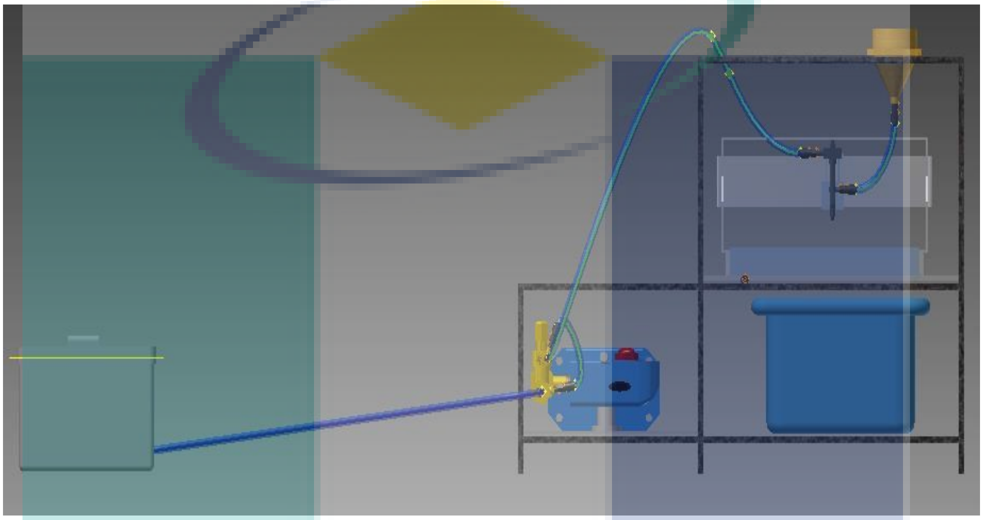

Figure 2: Front view of Waterjet Machine

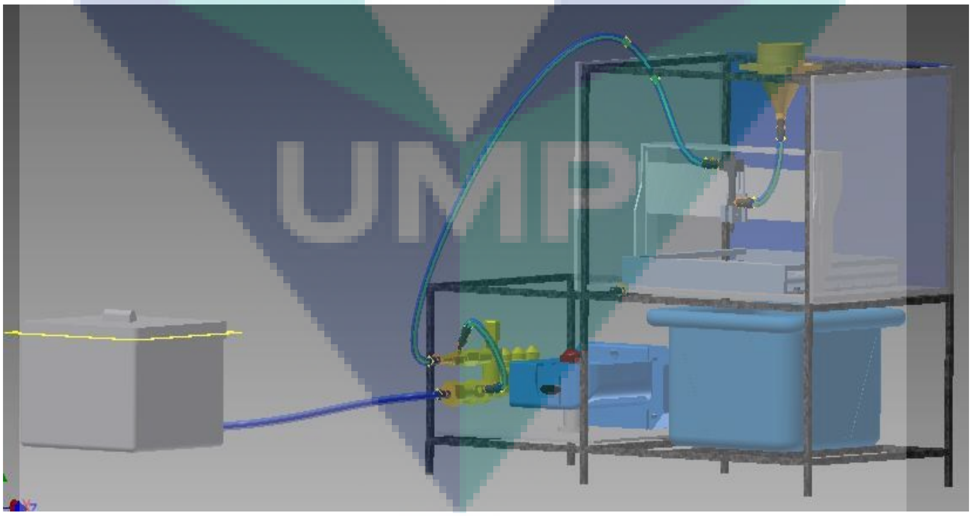

Figure 3: Isometric View of Waterjet Machine

According to the drawing of the water jet, the overall dimensions shall be 1007mm x 490mm x 743mm. The length and width result simply show that the drawing of this machine has meet the requirement list which is for length and width in ± 1000mm range. Thus the size of the waterjet machine is smaller and the further realization of waterjet machine will be in miniature size. The actual picture of the developed machine is shown in Figure 4.

Figure 4: Actual picture of developed machine.

The performance of the developed machine was accordingly tested. Firstly, the material to be tested is selected and the materials are machined in wedge shape of 30°. The material used in this investigation is Wood, Delrin (polymer), Aluminium (non-ferrous metal) and Mild Steel (ferrous metal). Further materials such as glass and ceramics will be used in the testing for further study. The parameters that will be varied is traverse speed (1mm/min, 2mm/min and 3mm/min) and other parameters such as hydraulic pressure (34 MPa), stand-off distance (5mm), abrasive flow rate (2 g/s) and abrasive type (garnet) are kept at constant. The orifice used is 0.152 mm in this investigation. A parameter table is established and experiments are carry out according the experimentation sequence. Once done with the machining, the depth of penetration is measured using digital Vernier calliper. The kerf taper ratio which is the ratio of upper kerf width to lower kerf width is calculated. Again digital Vernier calliper used to measure the kerf width. Then the surface roughness of the cut surface is measured using the surface roughness tester. The surface texture pattern and structure are observed using the Video Measurement System and Metallurgical microscope.

It is expected to cut soft materials at low pressure. However, the result proves that hard materials also can be cut. The depth of penetration on the material increases when the hardness of the material decreases. This is because, the abrasives particles have more energy than the bonding energy of the soft materials which causes more erosion on soft materials compared to hard material. From Figure 5, it can be seen that the depth of penetration increases when the traverse speed decreases. As the traverse speed increases; the nozzle will move faster where the water jets with the mixture of abrasives do not have enough time to cut fully. The contact time between the water jet and the material reduces. As a result, the water jet unable to erode the material fully and only able to cut a certain depth. Thus at low pressure, the material rate eroded would be less thus having a slow traverse speed can guarantee a longer contact time with the material for the water jet for better material removal rate.

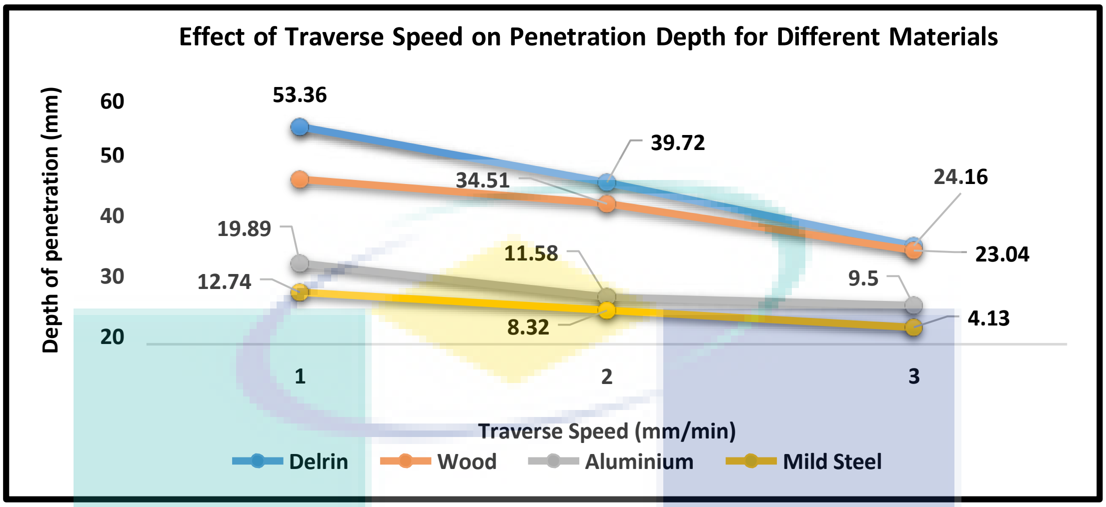

Figure 5: Effect of traverse speed on penetration depth for different materials

From the Figure 6, it can be seen that the kerf taper ratio increases as the traverse speed increases. This is because, when the traverse speed increases, the nozzles move faster where the contact time between the water stream and the target material reduces. Hence, the water jet does not have enough time to penetrate through the material that leads to wider upper kerf than the bottom kerf. At low traverse speed, the water jet would have more time to cut through the materials to give a wider lower kerf. At low pressure, utilising a lower traverse speed can give a smaller kerf taper ratio.

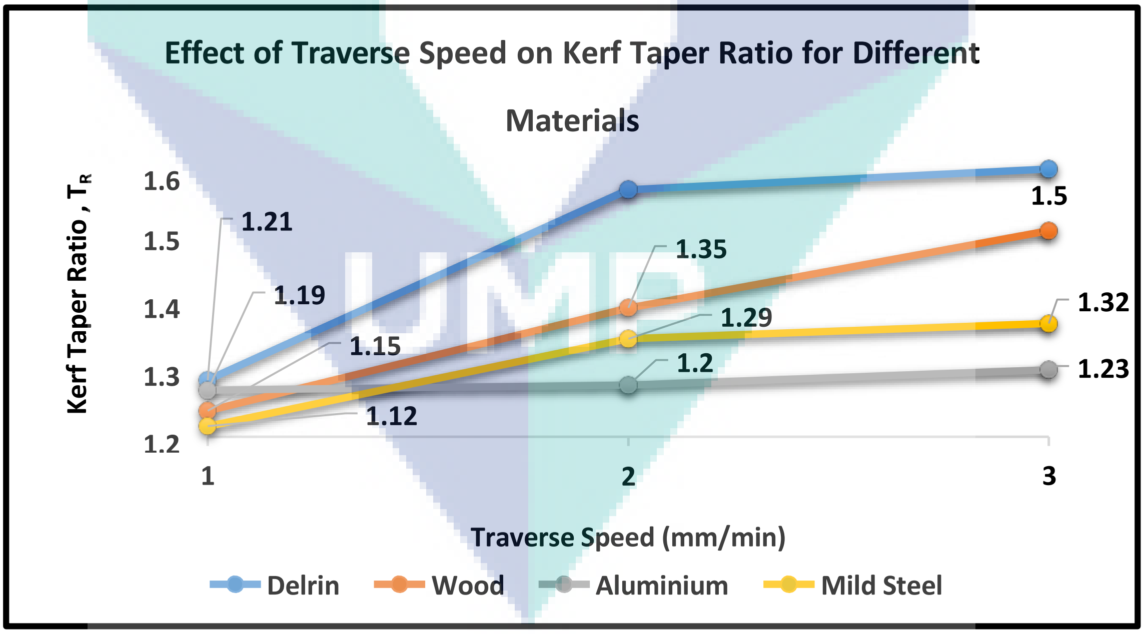

Figure 6: Effect of traverse speed on kerf taper ratio for different materials.

Figure 7 shows the increment in traverse speed leads to formation of rougher surface on the materials. This result is due to the abrasives particles that could not erode properly the target material as the nozzle moves in a faster traverse speed which results in the existence of surface roughness. At slower traverse speed, the AWJ have sufficient time to penetrate fully and erodes the surface properly which gives a smoother surface. At low pressure, slower traverse speed could aid the energised abrasives particles to impinge on the material and erodes at better rate.

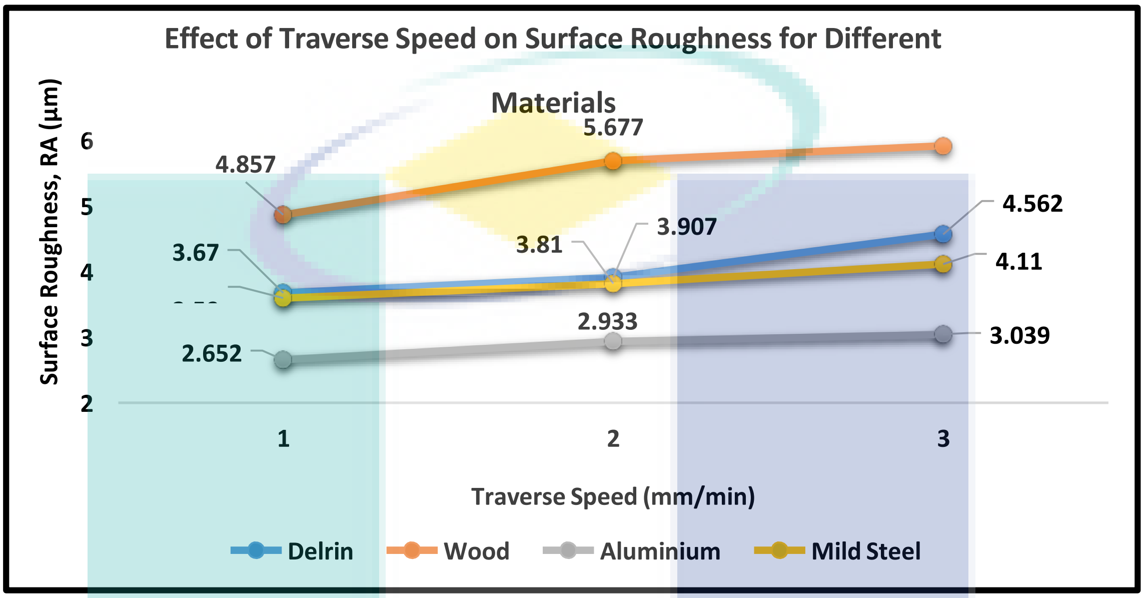

Figure 7: Effect of traverse speed on surface roughness for different materials

Bab 5 Kesimpulan & Cadangan

In conclusion, all the objectives for the "Development of Miniature Waterjet Machine" has achieved. The main purpose of this project is to develop a machine in miniature size. As the further realization of development of waterjet machine needed longer time inclusive purchasing and developing, the waterjet machine has been developed in virtual form. Through this project, the waterjet machine has been successfully presented in 3D modelling including its detailing for dimension and costing.

First and foremost, the first objective of developing waterjet cuter is to the machine in smaller size as the term of miniature is mentioned in the title. Firstly the function structure of waterjet is developed first. After that to determine the size for the whole machine, a study on types of router with its size has taken into account. The waterjet machine firstly is drawn in sketches. With exact dimension of 1007mm x 490mm x 743mm, the waterjet machine has been translated into 3D modelling with addition of specific materials. While the total raw cost for this project is RM. Hence the second objective is achieved which is to developed a miniature waterjet machine with reduce minimize cost.

The AWJ machining process at 34 MPa proves to be still in the range of machinability. At the low pressure, soft materials such as delrin and wood is cut and this is not something new. Since these 2 materials are considered as soft materials, low pressure cutting is still possible as the maximum depth of penetration of both of this materials exceeds 30mm. For harder materials such as aluminium and mild steel, the low pressure cutting at 34 MPa eligible to cut the materials. This can be considered as a leap to cut hard materials such as mild steel at low pressure. This feat is achieved with the aid of the lower traverse speed. The lower the traverse speed the higher the depth of penetration for all the materials. The decrease in traverse speed directly increases the depth of penetration and decreases the surface roughness and kerf taper ratio. Slow traverse speed gives the low pressure AWJ more contact time with material where more material will be removed which at the same time gives better surface smoothness. Thus, at low pressure cutting, utilising a slow traverse speed gives a higher penetration depth, lower kerf taper ratio and surface roughness.

Rujukan

[1] M. Hashish, D.E. Steele, D.H. Bothell, Machining with super-pressure (690 MPa) waterjets, International Journal of Machine Tools and Manufacture, 37 (1997) 465-479.
[2] A. Hace, K. Jezernik, Control system for the waterjet cutting machine, IEEE/AsME Transactions on Mechatronics, 9 (2004) 627-635.
[3] V. Richtlinie, 2223: Methodisches Entwerfen technischer Produkte, Verein Deutscher Ingenieure (Hrsg.): VDI-Handbuch Konstruktion, Berlin, (1999).
[4] V. Krishnan, K.T. Ulrich, Product development decisions: A review of the literature, Management science, 47 (2001) 1-21.
[5] R.P. Smith, J.A. Morrow, Product development process modeling, Design studies, 20 (1999) 237-261.