Adjustment of Mill CNC Parameters to Optimize Cutting Operation and Surface Quality on Acrylic Sheet Machining

by Sihar Tigor Benjamin Tambunan

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Adjustment of Mill CNC Parameters to Optimize Cutting Operation and Surface Quality on Acrylic Sheet Machining

Kuswara Setiawan [1, a], Sihar Tigor Benjamin Tambunan [2,b] and Pram Eliyah Yuliana[3,c]

[1] Universitas Pelita Harapan Surabaya, Indonesia

[2] Sekolah Tinggi Teknik Surabaya, Indonesia

[3] Sekolah Tinggi Teknik Surabaya, Indonesia

[a]kuswara,setiawan@uphsurabaya.ac.id, [b]tambunan@stts.edu, [c]pram@stts.edu

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Abstract. Acrylic is easy to machine. In addition to the advantages derived from the use of mill Computer Numerical Control (CNC) machine on acrylic sheet, there are at least two serious problems that need attention especially in cutting a small part with many vertices. These problems are the presence of excessive heat due to friction between the cutting tool with acrylic sheet on high RPM of spindle rotation, and soft acrylic flakes trapped in crevices of the cutting tools'flute.

Generally, the cutting process using a mill CNC machine often is a practice of trial and error. At least nine basic technical parameters need to be optimized. The effectiveness of the parameter values are determined by observing and measuring the actual cutting time using mill CNC machine at given parameter settings, surface texture quality, the level of clarity of the cuts, characteristics of chip formation, and edge roughness.

The experimental results showed that the adhesion of acrylic sheet and cutting tools is relatively low. However, the heat of cutting tool due to high spindle rotation, low feed rate, and relatively low melting point of acrylic, tend to form very small, soft, and hot flakes. The acrylic chips have great potential entering the crevices of cutting tools' flutes, and reducing the cutting power significantly. In other condition, the cutting tool could even be broken if feed rate is too high. Some technical values of these parameters are recommended to obtain optimal CNC based cutting operation and surface quality on acrylic sheet.

1. Introduction: Acrylic and CNC based Milling

Acrylic is an isotropic material that has a uniform mechanical characteristic, chemical, magnetic, and electrical property that are equal in all directions. Acrylic comes from the word,''acrolain'',that means strong odors. Acrylic is a thermoplastic, and glass-like plastic, non-metallic compound, synthetically made from organic ingredients. Acrylic is made of acid or glycerine aldehyde acrolain. Chemically, it is called polymetil methacrylate, made from petroleum, natural gas, or coal. This resin can be formed as long as it is on the plastic state, and will harden when heated due to the addition of polymerization reaction that occurs between the polymer and monomer. This material is provided for dentistry in the form of liquid and powder. Acrylic sheet with 10mm thickness or less is commonly used for works of art.

Some physical properties of acrylic sheet those considered for the CNC based milling process are:

- Hardness: 16-22 KHN, which means acrylic is an easily crushed/ etched, mechanically. The surface of acrylic sheet is very sensitive to lateral loads. Cracks easily occur.

- Thermal conductivity of acrylic is lower than metal (5.7×10^{-4}/sec/cm/^{0}C / cm^2).
- Acrylic can experience shrinkage whensubjected to polymerization and cooling. Linear shrinkage of 0.47 to 0.56%.
- The latter two thermal characteristics are of particular concern in this study because high speed cutting tools generate heat that could potentially change some of the characteristics of acrylic material being cut.
- Acrylic has cold flow (creep) properties, (ie. if the acrylic loaded or at a constant pressure and then removed, it will change shape permanently).
- Acrylic adhesion to metal is very low, so it needs a mechanical bond as in undercut or rough surfaces.
- Acrylic absorbs water of 0.45 mg/cm2, which can cause a linear expansion.
- Acrylic has no color or smell. Pretty good aesthetic properties, can be colored as required. Acrylic has no color and smell.

Recently one type of acrylic sheet processing that is used more frequently by several small and medium-scale enterprises in Indonesia (i.e.educational assembly/ disassembly toys and 3D puzzle producers) is a machining process using a small mill CNC machine (i.e.3 axis mill CNC). This is part of a forming operation by using a circular cutting tool with specific diameter (D) on specific cutting speed (CS) and tool diameter (D). Tool diameter is the first selection criterion for mill CNC tooling, while cutting speed (CS) is determined according to the type of material worked (in this study is acrylic), operation type, tool type, and tool material (Eq. 1).

$$CS = (CS\ value_{Material}\ x\ CS\%_{Operation\ Type})\ x\ CS\%_{tool}\ x\ CS\%_{tool\ material} \quad (1)$$

Feed per tooth of flute (FPT) works in much the same way (Eq. 2). The FPT value is calculated based on the material's base FPT multiplied by the Tool Type FPT percentage multiplied by the tool's FPT percentage.

$$FPT = (FPT\ value_{Material}\ x\ FPT\%_{Tool\ Type})\ x\ FPT\%_{tool}\ x\ FPT\%_{tool\ material} \quad (2)$$

Theoretically, the higher spindle speed (S) (Eq.3), the better the results. Unfortunately, the heat generated will also be higher.

$$S = \frac{3.82\ x\ CS}{0.5\ x\ D} \quad (3)$$

Feed rate (F) is influenced by spindle speed (S), feed per tooth (FPT), and number of tooth of flute (N). Theoretically, as shown in (Eq 4) below, cutting time will be shortened the higher the feed rate. However, the combination of high spindle speed (S), high feed rate (F), and low value feed per tooth of flute (FPT), can potentially cause high vibration on the acrylic sheet, which in turn could damage the parts or the acrylic sheet.

$$F = S\ x\ FPT\ x\ N \quad (4)$$

Plunge rate (feed rate on Z direction) should be set in such a way, so as not to damage or break the surface of the tool material due to acrylic cold flow characteristics.

The high temperatures in the process of machining acrylic is one condition that is not expected. Too much heat can cause the acrylic to expand and make it very difficult to control part size and shape. Cooling the cutting tool and the acrylic with water is not recommended. Acrylic, especially in flakes, is capable of capturing water molecules in large enough quantities. With water, debris that has hardened acrylic will block the side to be cut. Without water, soft and hot chips will go into the crevices of flutes.

In practice, the process of cutting more often is done by trial and error. This is called the art of machining because the cutting process parameters on the material must be combined very much. This happens because there are no standards regarding the effectiveness of the combination of cutting process parameters to produce optimal cutting results. There are at least nine basic technical parameters that need to be optimized; namely spindle speed (RPM), feedrate (mm/ min), the hardness of cutting tools (KHN), shape of cutting tools, number of flutes of cutting tools, diameter of cutting tools, acrylic hardness (KHN), cutting depth (mm), and the direction of cutting.

In this study, a number of experiments were performed by combining nine parameters to produce optimal cutting results on acrylic sheet. There are several attributes that determines the performance results of this study (i.e.criterion determining the optimum cutting results).

The attributes are cutting time, texture of cutting outcome (visual record), clarity of cutting outcome (visual record), chip form (visual record), and edge roughness (visual record).

2. Machining with SIC-330 Mill CNC

Actually, there are two basic mechanical process technology that can be utilized for the purposes of this study, namely the process of milling and the turning processes. According to the higher process complexity, the mechanical milling process technology using a SIC-330 Mill CNC machine was chosen in this study. It has a 3 control axis, feed rate of 600mm/min with accuracy 0.001mm, spindle speed up to 24,000 RPM, and with the power of a motor of 1500W (Fig. 1). The process of milling was the machining/ forming process utilizing material hardness of cutting tools, linear motion and rotational motion to form materials with lower hardness.

Fig.1 SIC-330 Mill CNC

The effectiveness of the cutting tool rotational motion is strongly influenced by shape and number of cutting edges (i.e.flutes), and rotational speed (i.e.spindle speed) as shown in Fig.2.

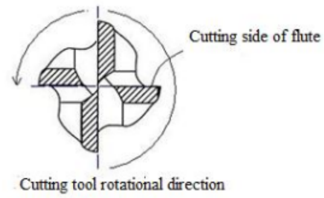

Fig. 2 Cutting Tool Cross Section [3]

In addition to the selection of the optimal tool [2], setting the cutting depth, cutting direction, and speed of linear motion tools, are the three process parameters that will determine the outcome of the cutting texture [1][5]. Chip formation is part of the CNC machining process. Chip formation is a reference to look at the effectiveness of machining processes, including heat generation process affecting the cutting tool life and the size of the work force in the process of cutting, etc [4]. Shapes of chips formed by different combination of cuting parameters value, including the material machined, can be different. The chips can be discontinuous (from powder to small flakes) or continuous. Each shapes should be studied carefully because it often affects the whole machine function, cutting tool life time, and the quality of the end product. In practice, some mill CNC operators combine specific feed rate and spindle speed to develop larger chip but not powder. They found that the larger chip –compared to powder- is able to carry away more heat from the cutting tool.

This is a situation that is not favorable enough for users of a CNC-based machining process, when the processes they use are very parametric. it is referred to as a process of trial and error with unpredictable outcome. That is why it a more scientific approach is needed to ensure quality cutting results.

3. Experimental Method

The following is the outline of the research methods of this study to achieve desired objectives in accordance with the rules and prevailing scientific norms.

1. Prepare a number (n) acrylic sheet specimens
   Two factors that are expected to need special attention at this stage are the dimensions of the specimen (especially the thickness of the material) and acrylic sheet flatness.
2. Specify nine cutting parameter settings and set some reference values on each parameter.
   An additional factor that needs special attention at this stage is the physical condition of the cutting tool (i.e.flute) that was used in several experiments (Fig. 5). Flake shape and texture can be very different pieces outcomes.

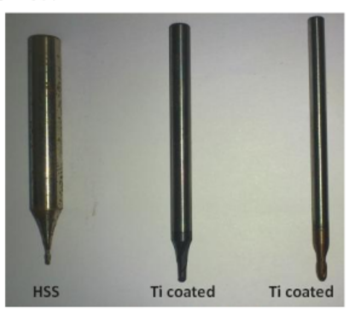

Fig.5 Some of cutting tools used in this study

3. Perform cutting simulation using CAD/ CAM software
   The factors to be considered are the design of the piece that will be used in the simulation. Some preliminary experiments showed that simulator program can not calculate the optimal effect of inhibiting the movement of the force when the cutting tool, through the (toolpath) contained many vertices
4. Perform a visual record of the results of the simulation of cutting and cutting time.
5. Make an NC program with the help of software CAD / CAM using MasterCAM software. Ensure that the G-code for dwells (G04 and P500, P750, etc) are adjusted to control the cooling time of cutting time.
6. Transfer the NC file transfer to the CNC machine's communicating software.
7. Do the material cutting process using Mach3 software and SIC-330 Mill CNC.
8. Perform a visual record of the results of cutting, cutting time recording, and sample of the chip.
9. Repeat the process 1-to 8 on some other parameter values
10. Conduct analysis of all visual recordings by recording a time of cuts, and recording achips form (Fig. 6).
11. Draw conclusions.

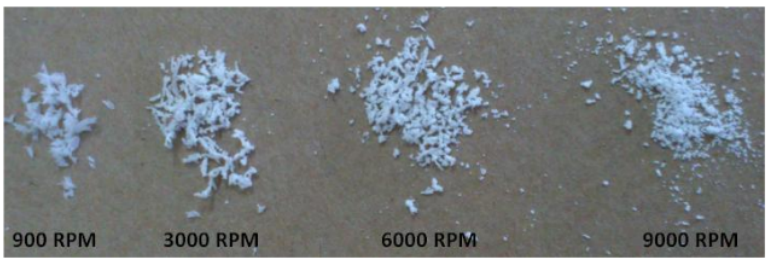

Fig.6 Chip formation on various RPM (Feed rate= 100 mm/ min, HSS flat endmill Ø2mm)

4. Conclusion

According to the findings of this study, the conclusions for the design of acrylic-cutting parameters using a mill CNC machine are:

1. Adhesion of cutting tool materials (HSS, Carbide, Ti coated) and acrylic was relatively low. However the heat of cutting tool due to high spindle rotation (above 9,000 RPM), low feed rate, and relatively low melting point of acrylic tends to form very small and soft flakes or chips.These can cause great potential entry into the crevices of cutting tools' flutes, and clogging them up, and reducing the cuting power significantly. Using different combination, the cutting tool could even be broken if the feed rate is above 200mm/ min.
2. Single flute is recommended. The use of cutting tools with flutes more than 2 is not recommended especially at high RPM.
3. In NC program, adding a dwelling G Code (G04 with specific P value) between parts is recommended. It is very important to wait the cutting tool to cool in between.
4. The addition of depth of cut (above 3mm/cut) can reduce the size of the chip. However, due to low hardness of acrylic, this parameter value must be combined with medium value of plunge rate.
5. Range of milling CNC feed rate was relatively large because the hardness of a cutting tool is much larger than the acrylic. However, it still must be controlled to avoid cracking of the acrylic due to lateral movement of cutting tool.

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