# ASSESSING SURFACE FORM OF EXPANDABLE POLYSTYRENE SHEET DURING HOTWIRE CUTTING

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## ABSTARCT

***Production of foam materials, such as expandable polystyrene, has been growing rapidly throughout the world as they have variety of uses. Some examples are in automotives industries, food packaging industries, medical application, sports gears, home insulations, and floatation in offshore drilling rigs, buoys and small boats. Since the uses of foam effects greatly to the daily lives of humans, the need to have foams in different shapes requires speed in cutting and speed in manufacture. This can only be done through computer-aided cutting machines or automated-cutting of foams. However, the speed of cutting will affect the surface finish or surface form of the cut. Therefore, it is necessary to determine the surface form of the polystyrene to achieve quality results. This is an on-going research to produce a rapid-prototyping machine, which cuts foam models. This paper illustrates the First Phase of this research, which is to determine the surface form of polystyrene through the use of Coordinate Measurement Machine (CMM), after being cut with different types of hot-wires, variable temperatures and diverse cutting speed.***

## INTRODUCTION

The market for foam material has been growing rapidly throughout the world. Foams can be categorized into two major types namely; flexible foams and rigid foams. The flexible foams are mainly used in furniture, transportation, bedding, carpet underlay, packaging, toys, sports application and shoes as well as for vibration and sound attenuation. The rigid foams are usually used in building appliances, insulation agent, pipes, tanks, floatation and food container [1]. The production of foams can take place by many different techniques. The most common method is producing continuous foam slab by pouring mixed ingredient of petro-chemical agent that include toluene diisocyanate, polyol and water. These ingredients are left to rise and cure. Additives are blended in for specific characteristics such as colours, absorbing capacity, effects on UV and others.

The above method produces foam in their 'raw' state. This state must be made into different shapes and sizes. This is usually done by cutting the foams into desired shapes and sizes. There are two ways of cutting foam materials, which are by using hot-wire techniques and oscillating blade method. Both produce different features to the foams. The oscillating blade produces simple geometrical shapes and is suitable for rigid foams. The hot-wire technique is capable for producing complicated geometrical shapes and is suitable for flexible foams. Presently, both techniques are performed either manually or semi-automated [2].

## OBJECTIVE

The main objective of this paper is to illustrate that a Coordinate Measurement Machine (CMM) is capable of assessing surface form of "soft" material such as polystyrene. Measuring surface form for soft materials is always a challenging task. Assessing surface form for "hard" materials such as metals are not complicated because there are many tests instruments exists. However, these instruments cannot be used to measure the surface form on soft materials.

This paper looks at the capability of a CMM to assess the surface form of soft foam materials like polystyrene. In this research, the polystyrenes were cut using hotwire technique with different cutting speed, different temperature and different types of wires.

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**COORDINATE MEASUREMENT MACHINE (CMM)**

Before further discussion, it is necessary to describe the features of a Coordinate Measurement Machine as a tool used in this research for determining the surface form of polystyrene. A Coordinate Measurement Machine consists of a probe to measure points on a workpiece. This is similar as when using a finger to trace a map coordinate. The probe acts as a finger that points or touches a certain location on the workpiece. Each point on the workpiece is unique to the machine's coordinate system. The coordinate system describes the movement of the measurement machine.

There are two types of coordinate system. The first is called the Machine Coordinate System. Here, the X, Y and Z-axis refer to the machine's motion. The second coordinate system is called the Part Coordinate System where the 3-axis relate to the datum of the workpiece. A datum is a location of a feature on a workpiece. It can be a hole, a surface or slot. CMM measure a workpiece to determine the distance from one feature to another. A CMM can also be used to determine the form or roughness on a surface of a soft object, such as polystyrene. The CMM used in this experiment is the Discovery Series Coordinate Measuring Machine Model D-12. Part of the programme used to manipulate the CMM in this research is illustrated as follows:

```
Sub Main()
  Startup

   Metric
   RemeasureOff
   Bilateral
   Rfs
   Cartesian
   TipFile "@Prbstrg@"
   Speed "254.000"
   OverDrive "58.000"
   Altitude "1.000"
   Backoff "2.000"
   Clearance "2.000"
   TouchSpeed "7.620"
   MoveTolerance "10.000,10.000,10.000"
   TouchTolerance "1.000,1.000,1.000".
   MLString "M9 A37.5,B180.0"
   MLString "PM @~Calign probe 1mm above front plate at L end to establish zero's@"
   Opwait "@Press [Record] to continue.@"
   ReadPosition "_PNT1"
   SetXYZOrigin "_PNT1"
   Measure_PLAN1
   PlaneXY
   Level "_PLAN1"
   SetZOrigin "_PLAN1"
   Measure_LINE1
   Offset "X,+X,_LINE1"
   SetYOrigin "_LINE1"
   Measure_PNT2
   SetXOrigin "_PNT2"
   MLString "PM @push PART button to get part alignment@"
   Opwait "@Press [Record] to continue.@"
   MLString "AM X-2.455,Y-59.135,Z301.194"
   MLString "AM X-2.453,Y-59.139,Z330.183"
   Measure_PLAN2
   Shutdown
```



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```
End Sub

Sub Measure_PLAN1()
    AddCommand "MP @take points on top of large area of angle.@,+z,4,0.000558,0.001759,0.999998"
    AddCommand "SF_PLAN1"
    SendCommands
End Sub

Sub Measure_LINE1()
    AddCommand "XY"
    AddCommand "M2 @2 points on front face of clamp plate.@,-y,2,-0.999995,0.003191,0"
    AddCommand "SF_LINE1"
    SendCommands
End Sub

Sub Measure_PNT2()
    AddCommand "QU @1 point on the end of the POLY.@;MV pr,0,0"
    AddCommand "SF_PNT2"
    SendCommands
End Sub
```

Figure 1 shows the design of the cutting tool produced in this research using a computer aided design (CAD) software, SolidWorks® 2001. The design and manufacture of this component was done internally in the Department of Mechanical Engineering.

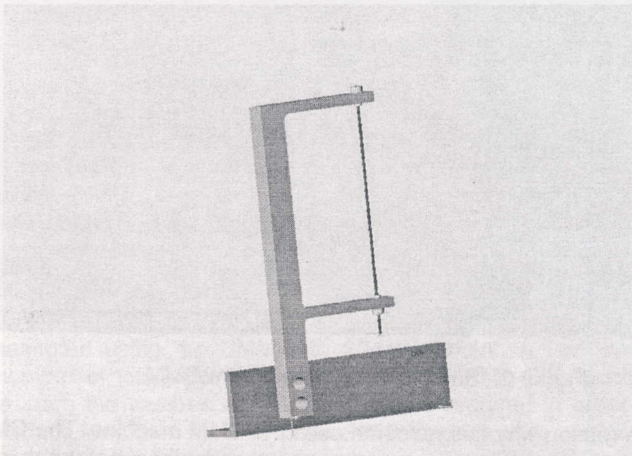


Figure 1(a). A diagram of the cutting tool drawn using SolidWorks 2001

## SURFACE FORM

The term 'surface form' or 'surface roughness' or 'surface texture' or even 'surface topology' are usually used to describe the 'smoothness' of certain substance. They usually consist of scratch marks and fragmentation marks. These marks are relatively spaced together and this makes them difficult to measure.

However, for soft materials, the most suitable term is Surface Form. Verifying the surface form of a polystyrene sheet is important because the surface being measured will be in contact with some other surfaces. By understanding its surface form, the nature of the contact and the performance of the contacted components can be controlled. If the surface form has to comply with a written standard, there are a few to choose from. The most common are the British Standard Institution BS1134: Centre-line Average Height Method for Assessment of Surface Texture, 1961. There is also another one being used in the mechanical engineering industry to date, which is the International Standard ISO 4287, 'Surface Roughness – Terminology – Part 1 – Surface and its Parameters'. First Edition 1984-12-15. However, these are more suitable for hard materials.

As mentioned earlier, questions are often raised concerning the possibility to measure surface form of soft materials such as polystyrene sheet or other foam materials. A common method is by using an optical technique (Figure 2). However, with the optical technique careful attention must be focused at local and steep slopes in the surface of the test piece. This is because the dynamic focusing instruments tend to produce corrupt feedbacks at these points. Other optical techniques encounter problems with steep local slopes by not reflecting enough light back into the detector.


Figure 2. Sample of test result from CMM

This is the main reason why this research uses the CMM machine. The CMM can measure the surface form of polystyrene because polystyrene usually does not have steep slopes. When examined through microscope, these slopes appear to be sperical in shape. Results of the tests are produced as shown in Figure 3. Noticed that the deeper the slope, the longer the line produced by CMM readings.

**EXPERIMENTATION**

In this research, a simple machine is designed to cut polystyrene using the hot wire technique. The machine will cut the polystyrene in 1-dimension movement (1D); that is, feeding the hot wire horizontally towards the polystyrene. Hot wire foam cutters are very common when working with polystyrene. The two ends of the hot wire are connected to a power source. Heat will flow when there is a difference in temperature across the wire. Heat flows from warm to cold areas at a rate proportional to the temperature gradient and the thermal conductivity of the wire it is flowing through. A thermocouple is connected to the hot wire to give a reading on the wire temperature. Manipulating the current and voltage of the wire can control the temperature. The temperature considered in this experiment is 100°C, 200°C and 300°C.

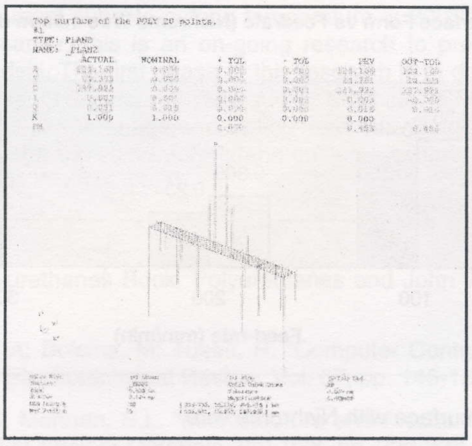



Figure 3. Sample of test result from CMM

The objective of this experiment is to reveal the surface form of polystyrene through the use of Coordinate Measuring Machine (CMM) with different types of wires, temperatures and cutting feed-rate. Surface form is affected by feed-rate and temperature of the hot wire cutter.

The test material was polystyrene with measurement of 300mm width, length of 300mm and thickness of 50mm. These sizes were selected due to the reasons that they can be easily handled when performing the test. The wire used as the cutting tool was Nickel Chromium Alloy (Nichrome), Inconel and Nickel-Chromium-Iron (NiCr-C) Spring Wire [3]. The reason for selecting Inconel and NiCr-C Spring wires are due to their ability to maintain their shape after being applied to the operating cutting temperatures [4]. Nichrome wire was chosen, as it is the most commonly used wire for cutting polystyrene materials.

The polystyrene was cut using different types of wires at different temperatures and feed-rate. The feed-rate ranges from 100 mm/min to 500 mm/min. After each cut, the surface of the polystyrene were measured using the CMM with 20-touch point. A test was done prior to this experiment on the number of touch points. Touch point from 10 to 200 touches were carried out using the CMM. The more the touches, the longer the time required in order to perform the test. Results shows that surface form from 20-touches and 200-touches were very similar. Therefore, this experiment chooses to accept the 20-touch points.

## EXPERIMENTAL RESULT

The following results could not be obtained without the use of a Coordinate Measurement Machine (CMM). In this research, the CMM is a vital instrument to interpret the surface form of polystyrene, which was cut using the hotwire technique.

The surface form of the polystyrene was recorded using different types of wires, temperatures and cutting feed-rate. Figure 4 shows that a Nichrome wire at a temperature of 100°C and feed-rate of 100 mm/min, produces a surface form of 0.551 units. The best surface form should be nearest to 0. Figure 4 also shows that the most suitable cutting temperature and feed-rate for Nichrome wire were 200°C and 200 mm/min respectively. Cutting can only be done, up to feed-rate of 300 mm/min. At a feed-rate higher than this, the wire tends to slip and bend. This affects the cutting quality and hence, the surface roughness of the polystyrene.

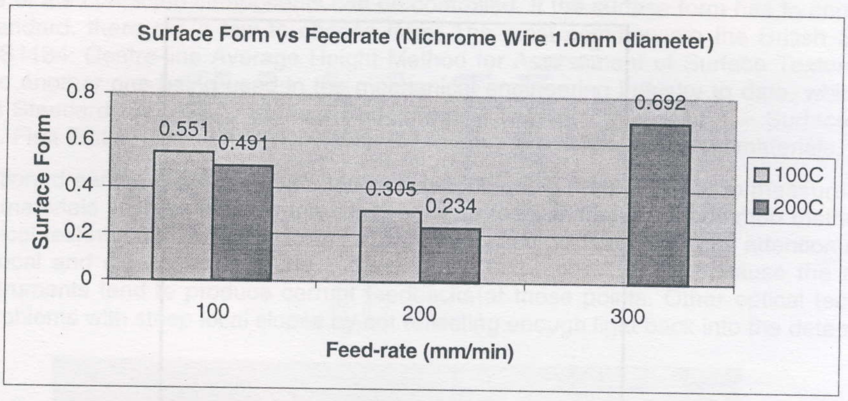
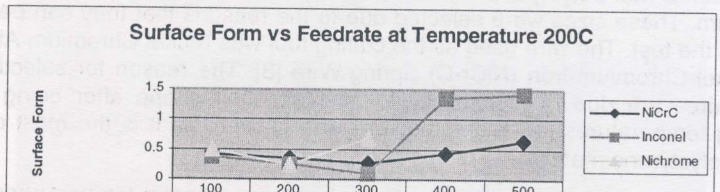



Figure 4. Cut surface with Nichrome wire

Figure 5 shows the cutting performance of all three wires at temperature of 200°C. At this temperature, two wires were able to cut up to a feed-rate of 500 mm/min, namely Inconel and NiCr-C Spring Wires. The best surface form was made from Inconel at feed-rate of 300 mm/min. However, NiCr-C produces a consistent surface form of below 1.0 unit at different feed-rates.




| | 100 | 200 | 300 | 400 | 500 |
|---|---|---|---|---|---|
| NiCrC | 0.412 | 0.344 | 0.266 | 0.423 | 0.644 |
| Inconel | 0.362 | 0.262 | 0.1007 | 1.352 | 1.415 |
| Nichrome | 0.491 | 0.234 | 0.692 | | |

Feed-rate (mm/min)

Figure 5. Surface Roughness of polystyrene with all wires

Based from the experiment, the best surface roughness was made from Inconel wire at cutting temperature of 200°C and cutting feed-rate of 300 mm/min. Inconel was able to perform cutting at a feed-rate up to 500 mm/min but the surface form was very poor.

A more consistent surface form was produced by NiCr-C Spring wire. The best surface roughness made from NiCr-C was at cutting temperature of 200°C and feed-rate of 200 mm/min. NiCr-C was also able to cut at a feed-rate up to 500 mm/min. An interesting outcome was, at all the different feed-rates, the surface form produced by NiCr-C was all below 1.0 unit. A consistent surface form made from different feed-rate is a good advantage as this will provide a secure cutting and prevent cutting error.

## CONCLUSION

The surface form of soft materials such as polystyrene can be determined using the CMM machine, with 20-touch point. Using the CMM, the best surface form was achieved by NiCr-C Spring wire, followed by Inconel wire. The most suitable cutting temperature is 200°C and cutting feed-rate of 200 mm/min. As mentioned earlier, this is an on-going research to produce a rapid-prototyping machine, which cuts foam models. The first phase of this research is to determine the surface form of polystyrene through the use of Coordinate Measuring Machine (CMM), after being cut with different types of wires, different temperatures and cutting feed-rate. Based from the result from this first phase experiment, the rapid-prototyping polystyrene cutting machine, which this research shall produce, will have NiCr-C wire is its cutting tool.

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