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EXPLORING THE ABILITY OF CUTTING EXPANDABLE POLYSTYRENE SHEET WITH LOOP HOTWIRE

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ABSTRACT

Foam materials such as expandable polystyrene sheet (EPS) have variety of uses. In order to optimise these uses, EPS are usually cut into different shapes and sizes. There are two ways of cutting foam materials, the Hotwire Technique and the Oscillating Blade Technique. Both produce different features to the foams. The oscillating blade produces simple geometrical shapes and is suitable for rigid foams. The hotwire technique is capable for producing complicated geometrical shapes and is suitable for flexible foams. This paper discusses an on-going research to produce a rapid-prototyping machine, which cuts polystyrene models using the Hotwire Technique. One of the phases of this research is to determine the surface form of EPS after being cut using a looped-shape hotwire foam cutter. The main interest is to explore the possibility of using a loop-shaped hotwire instead of the conventional straight-tensioned hotwire.

1. INTRODUCTION

Polystyrene is one of the most well known foam material. They are created from erethylene and benzine that can be injected, extruded or blow molded. It is a very useful and versatile manufacturing material. There are several types of polystyrenes that are suitable to be cut using hotwire foam cutter. The most popular are *expanded polystyrene* and *extruded polystyrene.* [1]

Expanded polystyrene (EPS) foam is used for coffee cups, insulation, packaging products for shipping, etc. It is made up of about 2% polystyrene and 98% air. It is manufactured by heating styrene pellets with steam. They expand rapidly within a mold and form a large block of low-density foam. The expanded beads remain as air filled-closed cells that resist the conduction of heat, and therefore are efficient insulators. EPS is light and very inexpensive. It does not degrade in normal circumstances because EPS is inert and has a very stable molecule. EPS can also be laminated to various other rigid materials such as plywood, plastics and metal to make panels [2]. Some of these panels are used in the construction of homes and light commercial structures.

Extruded polystyrene foam is the same chemical product as the expanded foam, but it is manufactured using a different process that extrudes the foam, resulting in a denser, more homogenous product with much smaller air pockets [3]. This type of foam is good for making signs and other display products.

2. SURFACE FORM

It has always been a challenge to measure surface form of soft materials such as EPS. Surface form consists of scratch marks and fragmentation marks. These marks are

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difficult to measure because they are located close to one another. Verifying the surface form of EPS 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.

The significance of measuring surface form of polystyrene is because polystyrene is a soft material. It is necessary to state that surface form and surface roughness is not the same. Surface form is a geometrical profile of a surface on soft materials, such as polystyrene or sponge. Surface roughness tends to be more useful for hard materials such as metals. Therefore, this research chooses to compare the surface form of polystyrene after being cut by a straight hotwire and by loop-shape hotwire.

A common method to measure surface form is by using an optical technique. 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 [4]. This is the main reason why this research uses the Coordinate Measuring Machine (CMM). The CMM can measure the surface form of polystyrene because polystyrene usually do not have steep slopes. When examined through microscope, these slopes appear to be sperical in shape.

A CMM consists of a probe to measure points on a workpiece. The probe acts as a finger that touches a certain location on the workpiece. The probe sizes that are available in our laboratory are 1.0, 2.0, 3.0, 4.0 and 5.0mm in diameter. The probe used in this experiment was ruby with size of 3.0mm in diameter. As polystyrene is soft, a smaller probe size may create new slopes or holes when touching the polystyrene. Larger probe size may not detect the existing slopes and holes on the surface of the polystyrene. This is the disadvantage of using a CMM.

3. EXPERIMENTAL TECHNIQUE

In this research, a simple machine was designed to cut EPS using the hotwire technique. The machine will cut the EPS in 1-dimension movement (1D); that is, feeding the hotwire horizontally towards the EPS. The hotwire was fashioned into a half-loop shape. The two ends of the hotwire are connected to a power source. Heat will flow when there is a difference in temperature across the wire, hence creating the hotwire. A thermocouple was connected to the hotwire to give a reading on the wire temperature. Manipulating the current and voltage of the wire can control the temperature. For example, based from this experiment, in order to achieve a temperature of 200°C, the values of current and voltage was 3.4 ampere and 4.0 volts. Having reached these current and voltage values, the thermocouple detects that the temperature of the hotwire was stable at 200°C, then only that the cutting was commenced.

The temperatures considered in this experiment were 200°C and 250°C and the cutting feed-rate was 250 mm/min. These were obtained from the previous experiments, which were completed in the early stage of this research [5].

The objective of this experiment was to investigate the surface form of EPS after being cut using a looped-shape hotwire foam cutter, through the use of Co-ordinate Measuring Machine (CMM).

The CMM used in this experiment was the Discovery Series Co-ordinate Measuring Machine Model D-12. Data were gathered by touching the test piece with either a solid probe or an electronic touch trigger probe. This experiment used the electronic touch trigger probe (Fig. 1). The probe measurement was taken perpendicular to the test piece to obtain optimal result because probe tip 'skidding' will affect the reading of data. The stylus used in this experiment was ruby with size of 3.0 mm in diameter because polystyrene is a soft material. As mentioned earlier, a smaller stylus size may create new slopes or holes when touching the polystyrene. Larger stylus size may not detect the existing slopes and holes on the surface of the polystyrene. Therefore, stylus with 3.0 mm in diameter was used to avoid the above reading errors.

The test material was EPS sheet with measurement of 200 mm width, length of 300 mm and thickness of 30 mm. These sizes were selected due to the reasons that they can be easily handled when performing the test. A Computer Numerical Control (CNC) machine was programmed to cut at 5 mm deep on the EPS sheet. The loop diameter was 30 mm and the step-over was 5 mm each cut. The wire used as the cutting tool was Nickel-Chromium-Iron (NiCr-C) Spring Wire. The wire diameter was 1.0 mm. The reason for selecting NiCr-C Spring wires are due to their ability to maintain their shape after being applied to the operating cutting temperatures [6, 7].

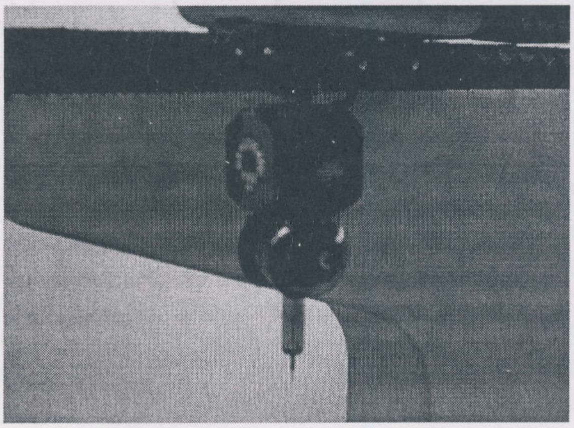

Figure 1: Probe used in this experiment

The apparatus required to perform the test was as follows:-

i. Hotwire cutter fixture. Designed as an 'L'-shape so that the vertical stem of the cutter frame could be connected to a CNC milling machine spindle housing. Figure 2a shows the 'L'-shape hotwire fixture with half-looped wire mounting holes. Teflon bushes were used to electrically isolate the hotwire from the metal 'L' frame.

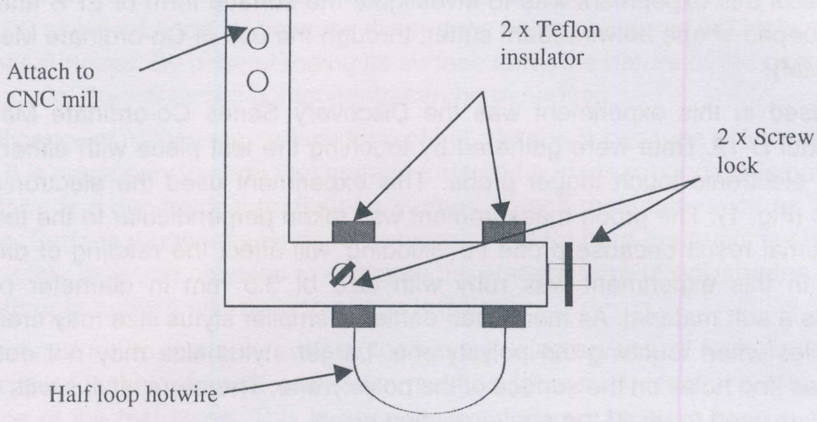

Figure 2a: Diagram of the 'L' shape hotwire cutter fixture

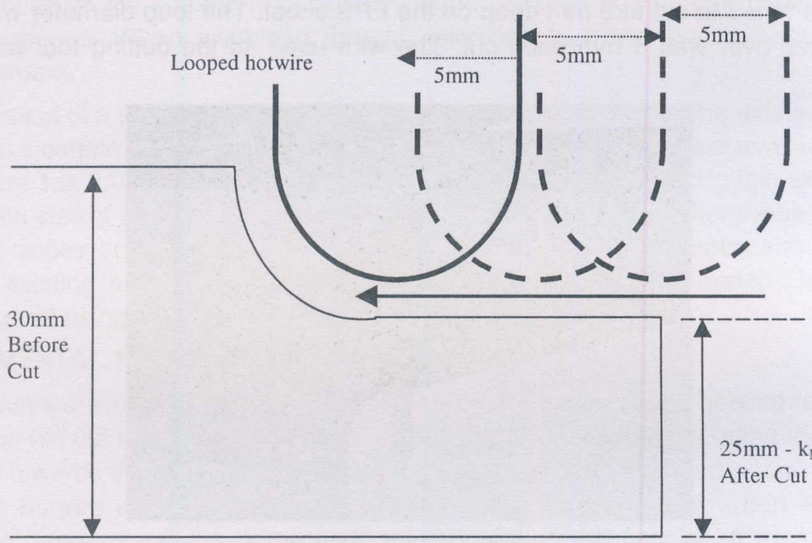

Figure 2b: Detail cuts at 5 mm step-over

ii. <u>Foam mounting fixture.</u> So that the foam sample could be relocated precisely in the milling machine and CMM successively, a special fixture was developed onto which the foam sample was permanently mounted.

iii. <u>CNC milling machine.</u> A standard industrial milling machine was used to ensure that the feed-rate and linear movement of the hotwire fixture could be accurately applied and manipulated as desired.

iv. <u>Power source.</u> The wire temperature was regulated by means of the applied voltage level.

v. Coordinate Measuring Machine. Measures for surface form were established with a computer controlled CMM.

vi. Temperature sensor. A thermocouple based temperature sensor was used to record the hotwire temperatures.

The thermocouple used was the K-type. This is a metal based thermocouple system using nickel alloys. The positive is Chromel and the negative is Alumel. Its useful temperature application ranges from 95°C to 1260°C.

The polystyrene used in this research was the General Purpose Polystyrene with density of 1.05 g/cm3, melting temperature of 80°C and tensile modulus 1.8 GPa. The original thickness of the polystyrene was 30 mm.

4. RESULT

The machine performed ten cuts on the EPS continuously at step-over of 5 mm each cut and 5 mm deep (Fig. 2b). After cutting, the surface of the EPS was measured using the CMM with 20-touch point. Due to the reason that heat from the hotwire dissipates the EPS while cutting, a Heat-affected Zone (kN) occurs. This can be calculated using readings from the CMM.

Original thickness of EPS, TO = 30 mm

EPS Thickness after cut, T1 = TO - 5 mm deep

Actual EPS thickness after cut, TA = Record from CMM

Heat-affected Zone, kN = T1 - TA

There were a total of 120 cuts performed on four EPS testpiece (TN) namely T1, T2, T3 and T4. Outcome of the cutting tests using looped-shape hotwire were plotted into graphical form. Figure 3 shows the comparison of thickness 'before cut' and thickness 'after cut'. The thickness after cut was measured using the CMM through the surface form of the EPS. Theoretically, the thickness after cut should read 25 mm because the original thickness is 30 mm and the depth of cut is 5 mm deep. However, accurate reading from the CMM reveals that the actual thickness after cut were slightly less that 25 mm. This is due to the heat-affected zone. From this experiment, the value of heat-affected zone is less than 0.5 mm (Fig. 4). Note that test specimen T1 and T2 achieved higher value of heat-affected zone. This is because the cutting temperature performed on T1 and T2 was 250°C, whereas cutting temperature for T3 and T4 was 200°C. Therefore, test specimen T3 and T4 produced a lower heat-affected zone. The surface forms of EPS were compared between cutting with straight wire and cutting using looped-shape wire. The type of wire remains the same.

5. DISCUSSION

During earlier stage of this research, we have performed a number of cutting tests on EPS using straight wire [8]. Their surface forms were recorded and compared with this latest experiment using looped-shape wire (Fig. 5). A surface form with lower value shows that

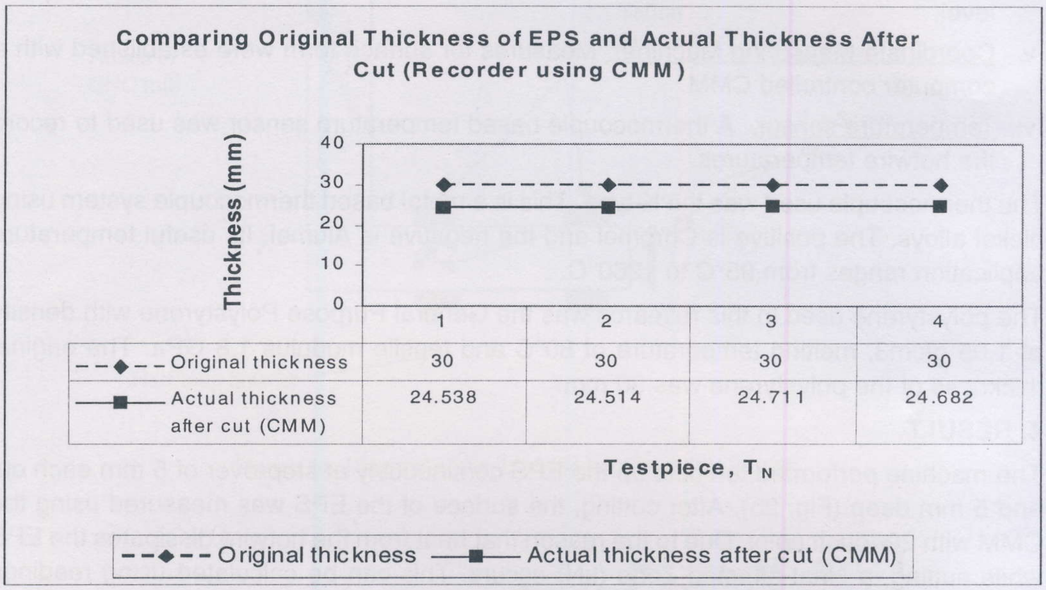

Figure 3: Comparing Original Thickness and Actual Thickness (CMM)

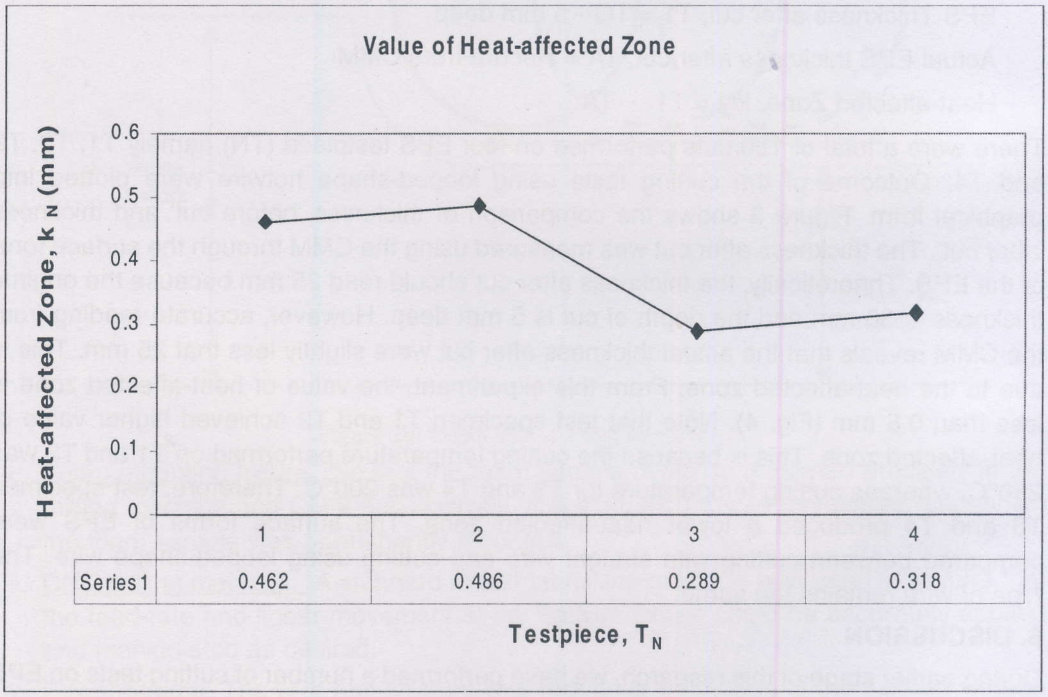

Figure 4: Value of Heat-affected Zone, kN

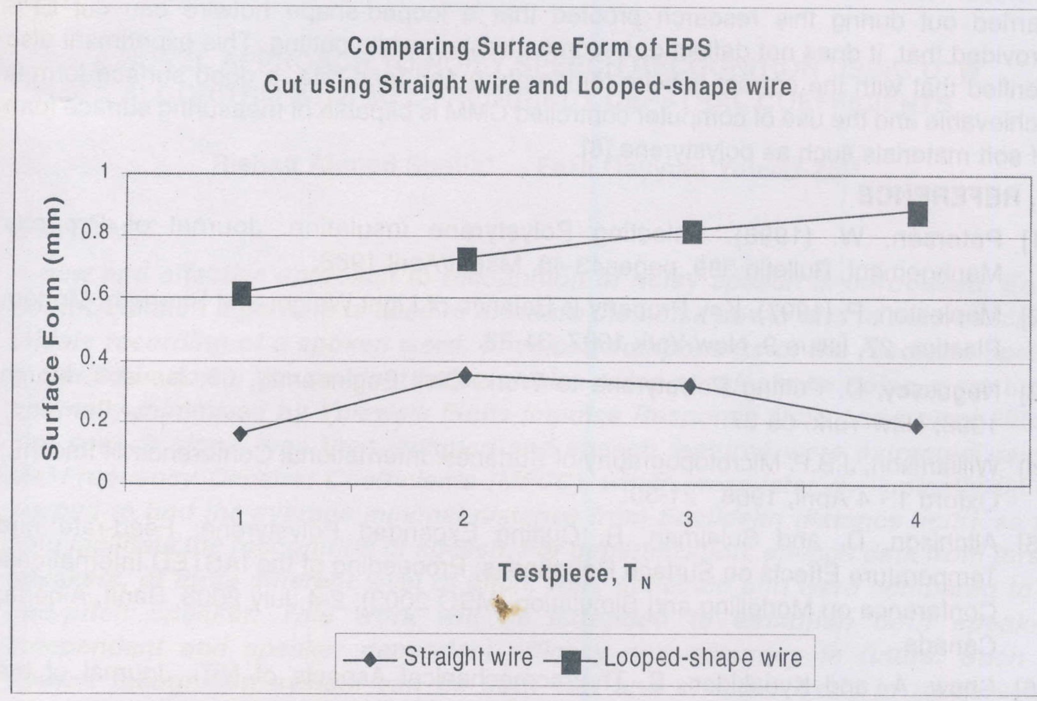

Figure 5: Comparing Surface Form of EPS (Straight wire vs. Looped-shape wire)

the surface is smooth, flat, or even. The lower the surface form, the smoother the surface. From this research, the surface form of EPS sheet cut by straight hotwire produced lower value of surface form. The surface of the EPS is much smoother.

The surface form of EPS cut using looped-shape wire tends to be more prickly compared to the surface form of EPS cut using straight wire. This is mainly due to the shape of the loop and the length of the step-over between each cut. As mentioned earlier, the loop diameter in this experiment was 30 mm and the step-over was 5 mm each cut.

It was found that smaller step-over creates more wavy and prickly profile on the EPS sheet. As the CNC machine performs the cut, it moves hotwire cutter horizontally, skimming the EPS sheet back and forward. The feed-rate of the CNC machine was 250 mm/min and the step-over was 5 mm. This makes the hotwire heat the 'same spot' more than once. Hence, producing more wavy and prickly surfaces.

The main concern during this experiment was that the looped-shape wire might deflect while performing the cutting process. However, this did not occur during the actual cutting test. This is due to the reason that the type of wire that was selected in earlier stage of this research was correct (Nickel-Chromium-Iron Spring Wire).

6. CONCLUSION

This paper discusses an on going research to produce a prototyping machine that cuts EPS sheet using the Hotwire Technique. One of the phases of this research is to assess the surface form of EPS after being cut using a looped-shape hotwire. Experiments carried out during this research proofed that a looped-shape hotwire can cut EPS provided that, it does not deflect or becomes twisted, while cutting. This experiment also verified that with the correct hotwire temperature and feed-rate, a good surface form is achievable and the use of computer controlled CMM is capable of measuring surface form of soft materials such as polystyrene [8].

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