Influence on Kerf Width in Machining Polystyrene by Heating Element Profile Maker using Nichrome Wire

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Abstract: - **Heating element profile maker is a designed on the basis of the non-traditional machining process. This paper represents the investigation on the effect and optimization of machining parameters on the kerf width and material removal rate. The experimental studies were conducted under varying current keeping voltage constant. The electric power transmitted to the wire is modulated to keep the wire temperature constant. Since the feed rate and kerf width both directly depends upon the wire temperature.**

Keywords: - Heating Element Profile Maker, Nichrome Wire, MRR, Kerf Width and Current.

1. INTRODUCTION

Heating element profile maker is Non-Traditional Machining process. Non-Traditional Machining processes are defined as a group of processes that removes excess material by various techniques involving mechanical, thermal, electrical or chemical energy or combinations of these energies but do not use a sharp edge cutting tool as it needs to be used for traditional machining processes. Extremely hard and brittle materials are difficult to machine by traditional machining processes such as turning, drilling, shaping and milling. Non-traditional machining processes, also called advanced manufacturing processes, are employed where traditional machining processes are not feasible, satisfactory or economical. Several types of non-traditional machining processes have been developed to meet extra required machining conditions. When these processes are employed properly, they offer many advantages over traditional machining processes. A new group of foam cutting rapid manufacturing machines are emerging, which have the ability to increase the complexity of object sculpted in foam. Mostly adopted method is the use of the layered manufacturing process in which the objects are built up from relatively thick layers of materials [4, 10,].In this process the tool and the work piece are located such that there is a gap of 0.1mm to 0.5mm between them. The tool is in the form of wire. The tool material is nichrome. It contains 80% nickel and 20% chromium. This tool material is also called as resistance wire. Work piece revolve along its axis. A power supply is used with 25A 12V DC.

2. LITERATURE SURVEY

So many research papers and articles are published on hot wire technique, to investigate the effect of process parameter on performance of process. The material investigated in hot wire technique are mostly of polystyrene and polyurethane, and tool material are of nickel and chromium alloy which are hard and have good thermal conductivity as compare to any other material. Different author use different combination of process parameter. They analyses the experiment data by plotting response curves for accuracy. Wilson Nunes dos Santos (2005) studied behaviour of thermal properties of melt polymers by the hot wire technique. In result the thermal conductivity and specific heat for the set polymers were studied [1]. N. Srinivasan and Y.V.R.K. Prasad studied temperature ranges and strain rate ranges for the characteristics of nichrome. In the result he discusses the inhomogeneous recrystallized bands at high temperature for the specimens deformed at a specific strain rate [2]. R. Coquard, d.Baillis, D. Quenard (2006) studied the experimental and theoretical study of the hot-wire method applied to low-density thermal insulators. They developed two dimensional stimulation of heat transfer and the classical hot-wire apparatus are poorly adapted to measurement on thermal insulators whose density is lower than 50 kg/m^3.They also concluded that the minimum length of 0.2m is required in order to make satisfactory measurements[3]. David r. Aitchison, Hadley L. brooks, Joseph D. Bain and Dirk Pons (2010) studied the “Rapid manufacturing facilitation through optimal machining prediction of polystyrene foam”. In this general relationships between wire temperature, power input, feed-rate, kerf width and work piece material composition were developed and an optimal machining algorithm was proposed and tested [4]. David Aitchison, Hadley Brooks, Joe Bain, Dirk Pons, “The Investigation into the prediction of optimal machining conditions for polystyrene foam cut with a taut hot-wire”. Through the cutting trials the cutting force for each sample was measured and logged with respect to time. Three stages 1, 2, 3 where considered in it. These stages represent the relation between the time and forces during the experimentation. It was observed that the kerf width vary between 1.4 to 6 times the diameter of the hot wire. A new parameters were developed called as the volume specific effective heat input and the mass specific effective heat input. A hot-tool cutting calculator (HCC) was developed. It was concluded that the method of incorporating the equations embedded in HCC into CAM software was suggested to attain high accuracy and speed level [5]. F.A. GARDER, "the possible influence of order-disorder transformations on the swelling of 85Ni-15Cr Nichrome alloy". It was postulated that the chromium addiction to nickel lead to some form of radiation enhanced micro segregation both above and below the order- disorder transformation temperature. In the experimentation it was concluded that ordered alloy can be developed which will exhibit low swelling and creep rates in fusion neutron environments. It was also shown that chromium addiction appear to depress swelling in nickel initially but also appear to suppress the tendency for swelling to saturate at high exposure[6]. Alessandro Franco, "An apparatus for the routine measurement of thermal conductivity of material for building application on a transient hot- wire method". An experimentation was performed to measure the thermal conductivity of samples of non-metallic materials whose thermal conductivity were lower. Thermal conductivity where measured by tracking the thermal pulse propagation induced in the sample by a heating source consisting of a nickel alloy wire. The thermal conductivity was measured in the range of 0.2- 1.5 W/m K. with the accuracy level of 5 % [7]. Imam H. Kazi,[*], P.M. Wild, T.N.Moore, M.Sayer, "Characterization of sputtered nichrome (Ni-Cr 80/20 wt. %) films for strain gauge applications". In this paper the electromechanical properties of nichrome films have been presented. The variations of sheet resistance, resistivity, gauge factor and Temperature coefficient of resistance (TCR) with thickness were presented. The 10mm thick film showed low resistivity, low gauge factor and a high temperature coefficient of resistance (TCR). The TCR decreases with the increase of the thickness up to 25mm [8]. H. L. Brooks and D. R. Aitchison, "force feedback temperature control for hot-tool plastic foam cutting". In the paper it was defined to control the wire temperature by vary current. The control strategy is implemented by making a series of one-dimensional cuts with a hot wire. Cutting condition used in this experiment the variability in kerf width was reduced from 1.5 to 0.1mm, increasing the accuracy by a factor of 15 [9]. The development of the delayed reference control for hot-wire cutting of EPS in an attempt to improve surface quality and kerf width. This controlled strategy effectively changes the cutting tool feed rate by introducing delays in the time-dependent tool path. The magnitude of the delay depends on the cutting force through proportional- differential control. If the force generated due to cutting is obtained, little other research has been performed on the development of control strategies for hot-tool plastic foam cutting [11, 12].

3. WORKING PRINCIPLE

When an electric current of high density and low voltage is passed through the wire, it transforms electric energy into thermal energy and emits thermal radiations. The tool is stabilized in its vertical position with the support of Colum of the machine. The final shape of the work piece generated is approximately a negative mirror image of the tool. The work pieces used in this process are of polystyrene and polyurethane material. The work piece revolves along its axis on the circular disc. A power supply of 6A 220v 50 Hz 450Watt is used in it. This power supply converts alternative current (AC) into direct current (DC) of 25A & 12V. Overloading and Shot Circuit Breaker is installed in this power supply system to safeguard the system against variations in voltage and current. A temperature controller is also connected in this system to control the temperature of the wire by varying the current. A systematic diagram of the process is shown in the figure 3.1.

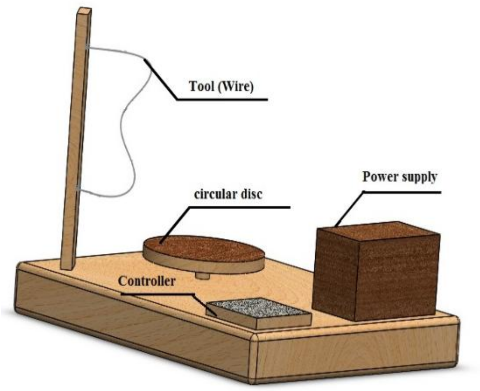

Figure 3.1:-Systematic Diagram of Heating Element Profile Maker.

4. DESIGN AND SETUP

Figure 4.1:- Setup of Heating Element Profile Maker.

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4.1 Geometrical Requirements:-

Material used: - wooden
Base: - Area: - 60cm ×71cm
Diameter of disc: - 14 inch (355.6mm)
Thickness of disc: - 5mm
Colum: - Length of section A: - (30mm)
Width of section A: - (20mm)
Height of section A: - (457.2mm)
Length of section B: - (30mm)
Width of section B: - (20mm)
Height of section B: - (90mm)

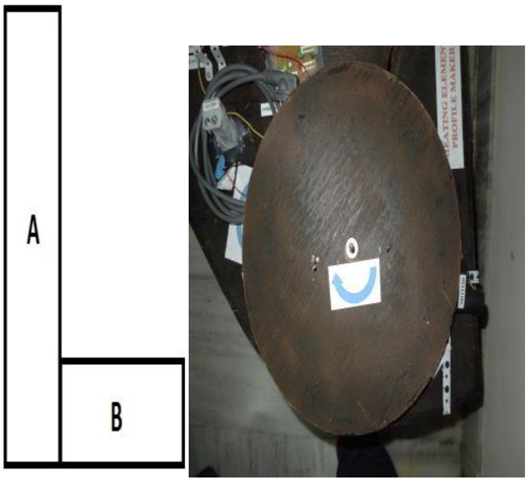


Figure 4.2:- Schematic Design of Heating Element Profile Maker.

4.2 Power Supply

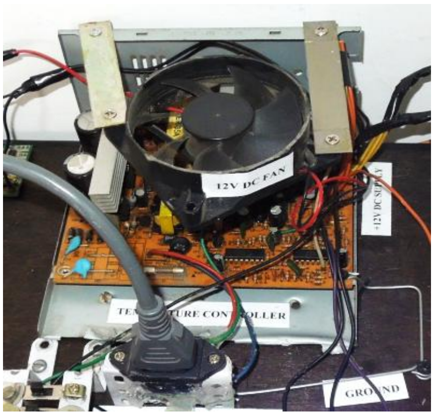


Figure 4.3:- Power Supply Circuit.

The power supply has a voltage range of 0 to 24Volts, a current capacity of 0 to 23 Ampere and can be used in constant current or constant voltage mode. Constant current mode is used for a regular surface finish. As shown in figure 4.3 and table 4.1.

Table 4.1:- Process Parameters & their Ranges

Parameter	Min	Nom.	Max
V_{in}(230 VAC)	180	230	265
V_{in}Frequency	47	50	63

5.PROCESS PARAMETERS

5.1 Current and Voltage

Current density depends on the temperature of the wire which is proportional to the applied voltage and work piece feed rate. As the tool approached the work piece the current density increases to maintained wire temperature. The gap maintained in the tool and work piece increases the current continued until the current was sufficient to maintain the temperature of the wire to attain a continuous material removal rate (MRR).

5.2 Flow Rate or Material Removal Rate

Material removal rate is dictated by melting of the polystyrene due the thermal radiation emitted by the hot wire. The selection of the ideal flow patterns and velocity was paramount for obtaining the best results. The gradient in the flow path directly affected the surface finish and depth of cut.

5.3 Temperature Control.

Since the thermal conductivity of the hot wire varies with the current density, so it must be maintained reasonably constant; otherwise the surface finish of the work piece will become irregular. For attaining a good surface finish the wire temperature was maintained at 150^0c.

5.4 Tool Design

As no tool wear takes place, any good conductor is satisfactory as a tool material, but it must be designed strong to with stand the high temperature during operation. The tool is made up of an alloy of nickel and chromium, so it is called as NICHROME. Nichrome is an alloy of 80%nickel and 20% chromium. The tool is a non-magnetic metal. The wire shape is design as a negative mirror image of the work piece to be formed. An outer profile is formed according to the shape of the wire. Tool mechanical properties are shown in the table 5.1.

Table 5.1:- Process Parameters & their Values

Material property	Value	Units
Modulus of elasticity	22 × 1011	Pa
Density	8400	kg/m3
Melting point	1400	°C
Electrical resistivity	1.0×10^{-6}	Ωm
Thermal expansion	14×10^{-6}	$°C^{-1}$
Specific heat	450	$Jkg{-}1°C^{-1}$
Thermal conductivity	11.3	$Wm{-}1°C^{-1}$

5.5 Work Piece Material:-

Table 5.2:-Work Piece Material Properties

PolystyreneProperties	
Density	1.05 g/cm³
Young's modulus (E)	3000–3600 MPa
Tensile strength(st)	46–60 MPa
Glass transition temperature	100 °C
Specific heat(c)	1.3 kJ/(kg·K)
Water Absorption (ASTM)	0.03–0.1

6. EXPERIMENTATION

When electric current is passed through an electrically resistive metal wire, the heat is generated in the wire. As a result the metal wire gets hot. This is known as the joule heating effect and is defined by equation (1).

$$Q = I^2 . R \text{ ………………… (1)}$$

Where the units of Q, I and R, are power (Watt), current (Ampere) and resistance (ohm) respectively [4]. In the case of hot-wire the heat generated can be defined as a linear volumetric heat flux as shown in equation (2).

$$Q_L = \frac{Q}{L_e} \text{ ……………. (2)}$$

Where L_e represents the length of wire in cut [4]. So that the relationship between the power input and the cutting speed may be shown, the effective heat input is described, as shown in equation (3).

$$Q_{eff} = \frac{Q_L}{V_c} \text{ ……………… (3)}$$

Where V_c is the cutting velocity in m s^{-1} and Q_{eff} has the units W.s m^{-2}. Ahn et al. from the Korea advanced institute of science and technology (KAIST) carried out a number of experiments investigation the relationship between the effective heat input, cutting speed and kerf width(Ahn et al .2003) [4]

The size of the work piece considered for experimentation is in 300mm × 300mm × 350mm. This study investigates the machining characteristics such as material removal rate (MRR).

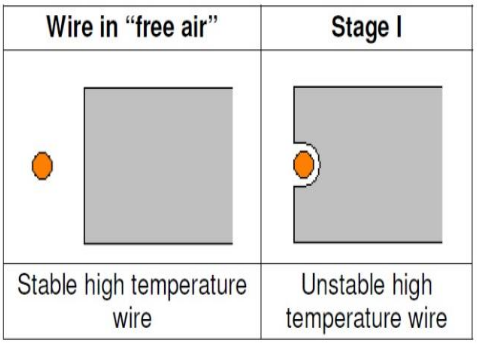
MRR = Kerf Width (k) × Thickness of work piece (T) ×Cutting Length (L)

Fig 5.1:-Before Machining and After Machining

7. CUTTING MECHANISM

Before cutting the wire is pre heated in free air for about 5 minutes to get a stable temperature of the wire. When the wire entered the work piece material the temperature of the wire get decreased. The colour of the wire changes from red to black, due to radiation of thermal energy of wire to the surroundings.

Following three stages are formed:-



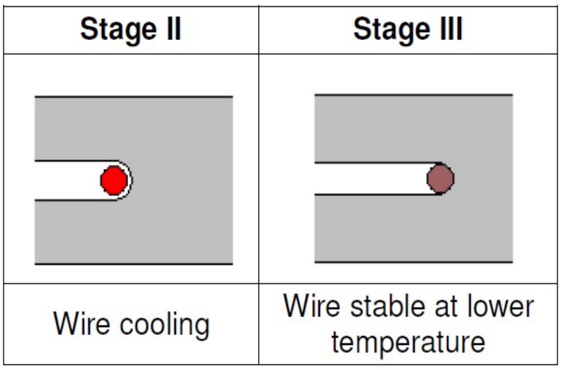


Fig: - 6.1 Stages

8. EXPERIMENTAL PARAMETERS

In the experimental work the performance parameters are feed rate, temperature of wire, current and voltage. Work piece material is of polystyrene with constant density of 1.05 g/cm^3. Wire diameter (Ø) 0.91 mm. kerf width units are in mm. four level are done with five experimentation. In the experiment voltage (V) is kept constant and current vary with 4A, 6A, 7A, 10A, 15A. In the experiment it is observed that the temperature of wire (tool) directly depends upon the current feed rate. The temperature (^{0}c) also increase with increase in current (A). Due to increase in temperature of the wire the vaporization of work piece (polystyrene) the feed rate also increases.

Table:-8.1 Performance Parameters

Cutting tool	Work piece material and density	Feed rate m/s	Temp °C	Cur rent (A)	Vol tage (V)
Ø 0.91 mm	Polystyrene 1.05 g/cm³	0.003	90	4 A	12 V
Ø 0.91 mm	Polystyrene 1.05 g/cm³	0.003	110	6A	12 V
Ø 0.91 mm	Polystyrene 1.05 g/cm³	0.004	120	7A	12 V
Ø 0.91 mm	Polystyrene 1.05 g/cm³	0.005	140	10A	12 V
Ø 0.91 mm	Polystyrene 1.05 g/cm³	0.005	165	15A	12 V

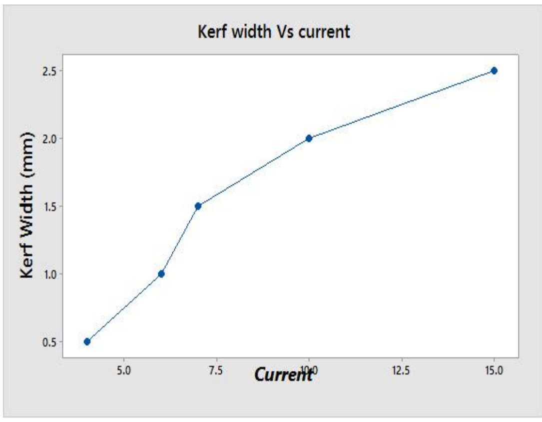


Figure: 8.1 - Variation of Kerf Width with current

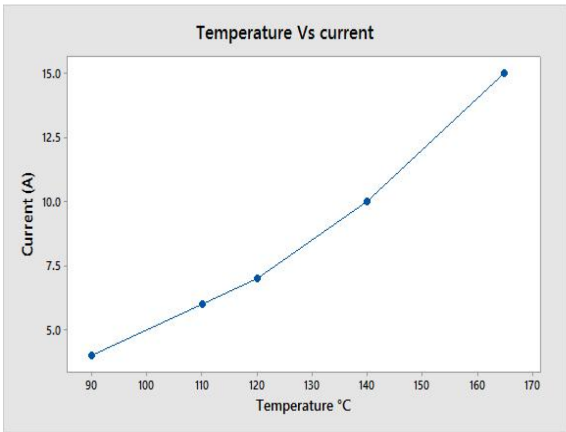


Figure:-8.2 variation of temperature with current

9. RESULT

The primary objective to design and optimize a prototype heating element profile maker was successfully completed. Towards the objective, a design approach was developed and subsequently carried out according to the standard design. In this experiment the wire can be drawn up into any required shape. The wire is heated up at 180-220^{O}c. Due to which it vaporizes the polystyrene material with coming in contact with it. A high MRR is attained with low kerf width. Voltage (V) in this experiment was kept constant at 12V. Current (A) varies from 4A, 6A, 7A, 10A and 15A.Figure8.1 shows the variation of kerf width with respect to current. In figure 8.2 variation of temperature with respect to current is shown. The feed rate also varies 0.003-0.005m/s as shown in Table8.1. The temperature of the wire depends upon the current feed rate. As shown in table 8.1 with increase in current the temperature of the wire (tool) also increases which resultsin the increase of kerf width. Figure 5.1 shows the work piece before and after machining.

10. CONCLUSION

In this paper, a design for a heating element profile maker has been presented. The key feature of the machine is to cut the raw material according to the requirement. The polyurethane or polystyrene material is cut by this process. The rise in temperature of the Nichrome wire vaporizes the polyurethane material as wire comes in contact with material. The temperature during the process is maintained at180- 220 ^{0}c. It was found that the temperature of the wire should be maintained at above said value for good surface finish.At 4A 12V the temperature of the wire reaches 90^{0}c and at 15A 12V the temperature reaches at 165^{0}c. But it was observed that with rise in current the temperature of the wire increases and kerf width also increases rapidly. But a high surface finish attained at 10A 12V. This was due to over rise in temperature of the wire at 15A 12V. This also increases the kerf width.

11. FUTURE SCOPE

With this machine the wax pattern can be design. These wax patterns can be used in investment casting. Investment casting is one of the oldest methods used for casting. These wax patterns are also used in dental science for fabrication of the teeth. This machine work manually, the work is define by the user and the temperature of the wire is also controlled manually. So this machine can be used at large scale industries by implementing the Computer Numeric Control (CNC) system in it. Work piece design can be formed in CAD/CAM software. Which will result in high accuracy and good surface finish.

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