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Experiment on high speed machining parametres for sport shoe sole mold making using aluminium alloy 5083, 6163 and 7075

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Properties

ABSTRACT

Purpose: The objective of this experiment is to obtain the fine surface roughness that is required less final polishing process as well as shortest manufacturing lead time.

Design/methodology/approach: the aluminum Alloy 5058, 6163 and 7075 are selected for the experiment on a high speed machine. The machine used for testing is namely Mold Maker 200&2500 which is the high precision machining center. Secondly, the study is emphasizes on the suitable cutting tool and cutting parameters. Accurate surface roughness measured level is an important factor for injection mold making. This section explains the process of surface roughness measurement on the machine, namely MarSurf XCR 20 V1.20-4.

Findings: The investigations are shown that the Aluminum graded Al 6163 and Al 7075 can be suitably used for the sport sole mold making in or to obtain the acceptable surface roughness without polishing

Practical implications: The method can be adapted for all global shapes of tools, even in the case of complex geometries

Originality/value: The investigations are shown that the Aluminum Al 6163 and Al 7075 can extremely save machining and polishing time.

Keywords: High Speed Machining; Sport shoe sole; Aluminium 5058

1. Introduction

High quality and short lead time processing is currently required for design and making sport lower shoe soles. Currently, aluminium alloy graded 5083, 6163 and 7075 are selected for making mould cavity and core injection plates in order to obtain the high quality of surface finishing. High speed machining is also widely used in order to obtain high machining productivity with uncoated carbide cutting tools. Therefore, the mould making lead time is extremely reduced. Roughness is a critical factor for mould making and polishing process takes time and in creased cost. The roughness is depended on material types, tooling types, cutting parameters and machining types. The high speed machining can make high quality of surface roughness and reduce cutting time. However, the levels of surface roughness requirements are based on suitable cutting parameter selection. In this case, the experiment is needed. Three material types are tested to obtain the good cutting parameters. The surface roughness is measured by the roughness measurement machine. On the other hand, the surface roughness of the existing mould which is made of tooling steel is measured. The both results are compared and investigate the cutting conditions which are occurred in the accepted conditions. The good conditions are applied to test on the mould flow testing conditions. The plastic mould processing time is calculated.

Sport shoe sole is nowadays used injection process instead of making by compression mould like in the past. The mould can be directly made which is compared to the compression mould. The mould is made based on the wood pattern. Therefore, the mould must be efficiently developed. It means that mould making leading time must be shortened. The most critical process of the mould making is surface roughness polishing. Therefore, the suitable material selection is very important. New material for mould making is taken into account such as aluminium alloy which is provided the good machining quality surface roughness. In addition, the modern machining process is used such as high speed machining. Chung et al. [2] studied the rapid fabrication of aluminium shoe mould using vacuum sealed casting. The technique is the most appropriate for the small-lot production system, because the production cycle is getting shorter owing to various needs of the customer. The casting process has ability to reflect complicated shapes in one process. However, it has not been widely used to make a mould and die because of the poor surface quality which is caused by air bubbles on the surface of the casting product. However, the experiment showed that porous casting mould is fabricated from a mixture of ceramic powder and water soluble binder. It can improve a high quality shoe mould which applies to RP&M – Rapid Prototyping and Manufacturing technology. Vallejos et al. [3] developed the framework to create a virtual organization breeding environment in the mould and die sector.

2. High Speed Machining

Many papers have shown the positive results of high speed machining. Ben et al. [1] studied the agility of high speed machining in terms of optimization between tool and holder. High speed machining technology (HSM) technology introduces cutting speeds that are faster than conventional machining. It increases process efficiency and obtains a good surface quality. HSM can reduce cutting forces; reduce heat transfer from work piece. In addition, the HSM can increase machining accuracy and metal removal rate. Lu et al. [5] presented the fabrication of ball end mill for high speed milling and its characterization. The investigation found that the ball end mill with negative rake angle and helix angle is most suitable for high speed milling. Gagnol et al. [6] expressed the dynamic analyses and design optimization of high speed spindle-bearing system by using MathLab together with FE method. The FE model monitored the rotor-beam element. Breton Et al. [7] identified cutting relations in high speed milling. This model aimed to improve the qualification procedure of a tool for milling a given material, considering first the local geometry of the cutting edge, and going back then to the global geometry of the considered tool or tool family. The method can be adapted for all global shapes of tools, even in the case of complex geometries. Lavernhe Et al. [8] presented the predictive model the kinematical behavior during 5 axis machining. The kinematical limits of the couple CNC machine tool have to be taken into account in the context of high speed machining. The model reconstructed the actual relative velocity tool-surface from each axis velocity profile highlighting trajectory portions. The high speed machining has several aspects of benefits. It can reduce machining time; reduce mechanical stresses; reduce heating of the part; improve surface finish; increase ability to use smaller tools; reduce assembly and storage costs; and improve dynamic stability.

3. Aluminium material properties and selections

Material to be used for mold making is one of the most significant criteria. Mostly, many types of tool steels are selected in order to obtain the long life cycle of production. However, business world is currently changing. Short product life cycle is occurred. Product varieties together with small quantity production are required. Therefore, the material requirements and selections are also changed. Materials which are less needed for polishing are preferred. Aluminum alloys are one of the most targets. This section discusses the different types of materials which are suitably used for shoe mold making. The tool steel of ExELL P-20 is compared to aluminum alloy which are graded 5058, 6063 and 7075.

The ExELL P-20 is a premium quality Cr-NI-Mo alloy tool steel which is normally supplied in the pre-hardened condition. The benefits include no heat treat costs, risks and time lost; lowest tooling costs; can be surface treated such nitride, frame hardened, plated, etc. The characteristics provide consistently high quality standard. They are good machinability, good polishability, good photoetching properties, uniform structure and mechanical properties. The applications are widely used such as injection molds for thermoplastics; large compression molds; plastic extrusion and film dies; blow molds; zinc die cast dies; holders for die cast dies; structural or engineered components with pre-hardened properties. The chemical composition contains carbon 0.35%; Ni 0.50%; Mn 0.85%; Cr 1.80%; Si 0.45% and Mo 0.50%.

Aluminum 5083 is a strong magnesium-manganese-chromium-aluminum alloy. It can be hardened by cold work, but is not heat treatable to higher strength. It has good ductility for the strength level, better than most other 5000 series of alloy. It has excellent resistance to general corrosion, and is used in marine applications. Resistance is excellent in aqueous solutions in the pH range 4-9. The corrosion resistance of aluminum alloys relies on a protective surface oxide film, which when damaged is readily repaired by the reaction between aluminum and oxygen. Alloy 5058 can be anodized to improve the corrosion resistance by thickening the productive surface film. The characteristics provide good formability; very good weldability; fair anaodising; fair machinability; but poor brazeability. The chemical composition includes magnesium 4-0-4.9%; manganese 0.40-1.0%; chromium 0.05-0.25%; silicon 0.40%; iron 0.40%; copper 0.10%. The applications are used for marine applications, unfired welded pressure vessels; TV towers, drilling rigs; transportation equipment and armour plate.

Aluminum 6163 is a medium strength alloy commonly referred to as an architectural alloy. It is normally used in intricate extrusions. It has good finish, high corrosion resistance, is readily suited to welding and can be easily anodized. The applications are typically used in architecture such as extrusions; window frame; doors; shop fittings; irrigation tubing; road transport, rail transport and sport equipment. The chemical composition includes Si 0.2-0.6%; Fe 0.35%; Cu 0.1%; Mn 0.1%; Mg 0.45-0.9%; Zn 0.1%; Ti 0.1%; Cr 0.1%.

Aluminum 7075 is a very high strength material which is used for highly stressed structural parts. The applications are used for aircraft fittings, gear and shafts, fuse parts, meter shafts and gears, missile parts, regulating value parts, worm gears, keys, aircraft, aerospace and defense applications such as bike frame, all terrain vehicle (ATV) sprockets. The chemical composition includes Cr 0.18-0.28%; Cu 1.2-2.0%; Fe 0.5%; Mg 2.1-2.9%; Mn 0.3%; Si 0.4%; Ti 0.2% ans Zn 5.1-6.1%.

4. Cutting tools and parameters

Cutting tools and parameters are directly affected to the quality of surface roughness. A ball nose is selected to tested in this study. The first parameters are taken from the tool manufacturers, namely SANDVIC. The general equations are as the followings:

$$n = \frac{1000 \text{ x vc or ve}}{\pi \text{ x Dc or Dc2}} \quad \text{rpm.} \qquad (1)$$

$$vf = n \text{ x fz x Zn} \quad \text{(mm/min)} \qquad (2)$$

$$De = 2 \text{ x } \sqrt{ap \text{ x } (Dc2 - ap)} \quad \text{(mm)} \qquad (3)$$

$$Ve = \frac{\pi \text{ x n x De}}{1000} \quad \text{(mm)} \qquad (4)$$

The typical shallow cut in HSM gives low cutting forces and defection. The heat generated into the cutting material and component is greatly reduced. The possibility chip thinning effect is given in order to increase speed and feed radically. In order to get a correct Ve and Ve and an optimized productivity, it is important to define the effective diameter in cut De. The linear dependence between cutting speed and feed rate results in high feeds with high speeds. To compensate for a smaller diameter the spindle speed (rev/min) must be increased to keep the same cutting speed and the increase spindle gives higher feed speed vf. In finishing with HSM it is possible to increase the cutting speed, vc , by a factor of 3-5 compared with conventional milling. This is due to the extremely short contact time between the cutting edge and the component. The heat generated is very small and so is the amount of efficient work per revolution. This normally gives a very long life, which in turn opens for big productivity improvements, as the feed speed is dependent of the cutting speed vc. very typical ae/ap values in finishing with HSM ranges round 0.2/0.2 mm. [4] described the high speed turning of Ti-6Al-4V alloy with coated carbides tools in an argon enriched environment. The cutting tool was a coated cemented carbide inserts [(Ti, Al) N TiN – ISO K10 grade]. The poor performance can be associated with the low thermal conductivity of argon, consequently leading to high concentration of heat in the cutting region which tends to accelerate tool wear.

5. Surface roughness measurment

Surface roughness is measured by the perthometer (Fig. 1). This is surface texture measuring station with concept contour. It serves for determining radii, distances, and angles on work-pieces. The program added is quite efficient which is performed on windows.

Fig. 1. The Perthometer Surface Texture Measuring Station

6. Shoe mold design and analysis

This section presents the shoe mold design and analysis. Mold is designed on CAD and analyzed by Mold Flow commercial software. The mold flow is a library computer program which is used to predict the flow of plastic into an injection mold. This tool gives the designer the ability to design molds and parts, knowing how the plastic will flow into the mold, and what effect this will have on the quality of the finished part. There are two aspects of moldflow, separate and independent which is expressed by the Moldflow handbook. The first aspect is the body of knowledge of plastic flow, and its effect on the quality of the finished part. The second is the computer programs which give a numerical basis to the concepts of flow. The context of the moldflow design philosophy is that mold design is based on mechanical considerations, i.e. arranging split lines, axis of the part to the machine, movement of sliding cores etc. Gating positions, and runner layout and dimensions are then decided to ensure the part will fill. As the designer does not have information about the pressure drops in the flow, they adopt a cautious approach. To be certain that there are often positioned throughout the part and the runners and gates are made large so the designer is confident part will fill. However, the plastic filling behavior to become the product based on the core and cavity is quite important. The next context is discussed the plastic flow and filling behavior.

As the ram of the injection machine moves forward, it first moves at a steady speed as the plastic flows into cavity. This is called the filling phase. The second phase is pressurization phase. This phase is occurred when the ram is moving, bringing the mold up to pressure. The ram is slow down when the mold is filled but it still moves some distances. This is because plastics are very compressible materials. At injection molding pressure an extra 15% of material can be forced into the cavity. The compressibility of plastic can be observed by blocking off the nozzle and then pressing the inject button. The ram jumps forward when the pressure is active. It is then spring back when the pressure is released. Although fluids are usually assumed to be incompressible, molten plastics have to be considered to be more like a gas. The third phase is compensating phase. It is occurred when the ram does not stop completely. It continues to creep forward for some time. Plastics have a very large volumetric change of about 25% from the melt to the solid. It can be seen in a short molding. The end of flow is all wrinkled and shriveled, the different in volume between the molding and the cavity being due to this volumetric change. This is the compensating phase because the volumetric change is being compensated for. As the volumetric change is 25% and only an extra 15% at the most can be injected in the pressurization phase.

Mold conditions are important to be taken into account. The first material to freeze off will shrink early in the cycle. By the time the material freeze in the rivers, the bulk of the material will have already frozen off and shrinkage will have occurred. The rivers will shrink relative to the bulk of the molding and because they are highly oriented, shrinkage will be very high. The result is high stress tensile members throughout the molding, the common cause of wraping. The effect of molding conditions is considered as the key mold setting of mold temperature, melt temperature, and fill time on part quality. The main aims must be minimal residual stress level, and the avoidance of both warpage and sink marks. At the low melt temperature there is a large pressure drop over the runners, so the actual pressure in the cavity will be indicated by low part weight. A small increase in melt temperature provides a big reduction in melt viscosity; hence the pressure drop in he runner will be less. Increasing mold temperature has a similar effect to melt temperature, except that the effect on pressures and stress levels are less marked until very close to the freeze temperature. The effect on cooling time can be much larger than an equivalent change in melt temperature is that it shows a slower injection rate, without the plastic getting too cold. Short fill times give high pressure simply because the flow rate is so high. Long injection times require high pressures because the melt temperature at the end of flow is so cold. Somewhere between these extremes is an injection time which gives an acceptable fill pressure.

In this study, the moldflow is used for the aluminum shoe sole mold analysis. Based on the Moldflow design philosophy, it uses the concepts of flow, and applied using the capacity of the Moldflow software to predict pressure, temperature, shear rate, shear stress and cooling time, etc. The procedures composed of the stages of decide number of gates, position of gates, flow pattern and runner design. The procedure for mold design always starts with the cavity. Number of decisions is needed until the cavity conditions are acceptable. Then, the Moldflow can investigate the optimizing molding conditions. It can predict pressures, temperatures, shear rates, shear stresses, cooling times, filling patterns, etc. The cavity dimensions are defined on CAD. The appropriate material data are taken from Moldflow's extensive database of plastic materials. The molding conditions are optimized for the mold geometry and materials.

7. Experimental study

The section presents the experimental study of different aluminum materials for making injection mold for sport shoe sole. Firstly, the aluminum Alloy 5058, 6061 and 7075 are selected for the experiment on a high speed machine. The machine used for testing is namely Mold Maker 200&2500 which is the high precision machining center. Secondly, the study is emphasizes on the suitable cutting tool and cutting parameters.

Accurate surface roughness measured level is an important factor for injection mold making. This section explains the process of surface roughness measurement on the machine, namely MarSurf XCR 20 V1.20-4.

Table 1 shows the surface roughness testing results which receive from the different cutting conditions and types of materials. The major cutting conditions are set up the machine spindle speed between 11,00 rpm. to 20,000 rpm., with the feed rate 500 m/min and 1,000 m/min. The result shows that the best surface roughness is 0.152 µm. The material type is Al 6163 with using the cutting conditions of 11,00 rpm of cutting and 500 m/min of feed rate. The second best result is 0.180 µm. which belongs to the material type of Al 7075 with using 11,000 rpm. of spindle speed and 500 m/min of the feed rate.

Table 1.
The surface rough testing results

Material	Cutting conditions		Surface Roughness			
	RPM	Feed	Lt	Ls	Ra	Rz
	Rpm/min	m/min	mm.	µm.	µm.	µm.
Al 5083	11.000	500	4.92	1.0	0.343	1.393
	20.000	1.000	13.96	2.5	1.207	4.752
Al 6163	11.000	500	4.98	1.0	0.152	0.612
	20.000	1.000	4.97	1.0	0.194	0.799
Al 7075	11.000	500	4.96	1.0	0.180	0.811
	20.000	1.000	4.94	1.0	0.487	2.472

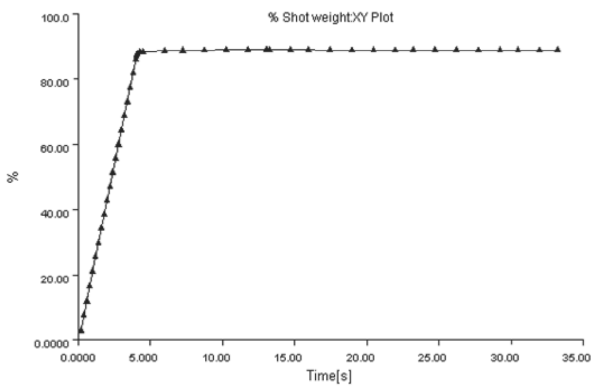

Fig. 2. The Short weight and time

Figure 2 shows weight of material filled into cavity and time. The filling weight is grown up rapidly at the first 5 second. After that, the filling weight is stable at approximately 80%. Figure 3 shows the average time for the material fulfillment. This experiment is tested on the conditions of using cooling system assistant. The result shows the average velocity time is 33.20 second.

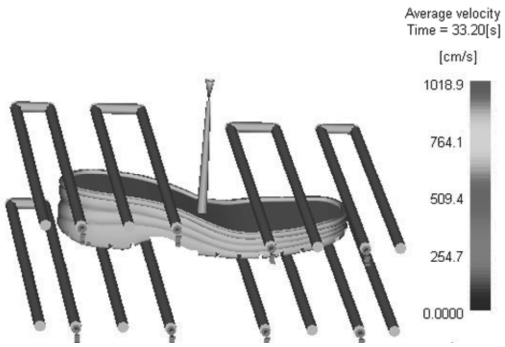

Fig. 3. The average velocity time

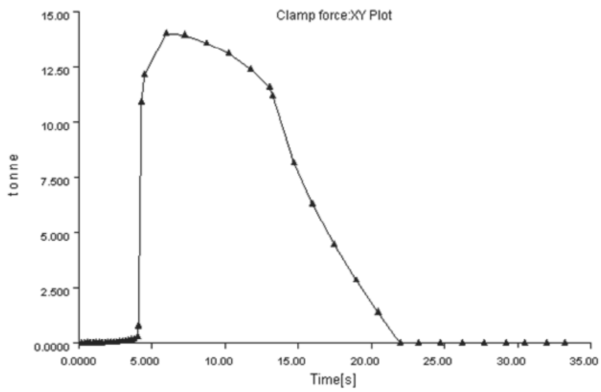

Fig. 4. The clamping force and time

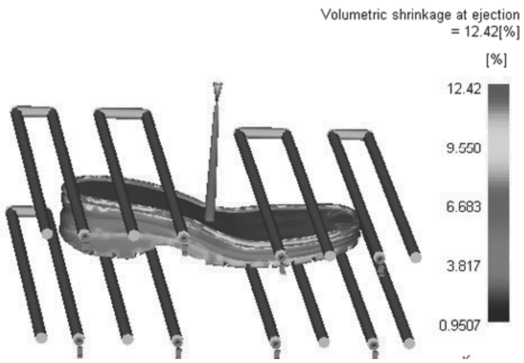

Fig. 5. The volumetric shrinkage at ejection

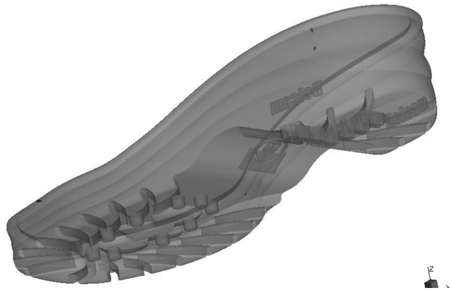

Fig. 6. The spot shoe sole model

Figure 4 shows the clamping force and time. The clamping force is started slowly during the first five minutes. Then, it is immediately increased until 12 tons of clamping force. It is continually grown by the relation between the clamping force and time for few seconds. Next, the force is slowly decreased by ten seconds. In the final stage, the force is rapidly decreased until it stops. It takes 22 seconds. Figure 5 shows the volumetric shrinkage at ejection. The simulation result shows the shrinkage occurs 12.42%. The Figure 6 shows the study model of sport shoe sole which is made by aluminum.

8. Results and discussion

It is clearly concluded from the experimental study that the material used for the sport mold shoe sole is the aluminum graded 6163. The machining parameters can be used both 11,000 rpm and 20,000 rpm. of spindle revolution together with 500 m/min and 1,000 m/min of cutting speed respectively. The experiment is tested on the high speed machine. The surface roughness which is received from the experiment machining is 0.152 µm. and 0.194 µm. are both the acceptable level for plastic injection processing. In addition, this experiment has found that the Al 7075 can be also used with the 10,000 rpm. of spindle speed by 500 m/min of cutting speed. It can receive the surface roughness of 0.180 µm. Then, the mold analysis by the mold flow analysis software is the followings:

- The average velocity time = 33.20 sec.
- The bulk temperature time = 33.20 sec.
- The bulk temperature at end of fill = 205.50 °C.
- The fill time = 4.08 sec.
- The flow rate, beams time = 33.20 sec.
- The in cavity residual stress in first
- principle direction normalized
- thickness = 0.9690 MPa.
- Pressure time = 33.20 sec.
- Pressure at end of fill = 11.42 MPa.
- The pressure at V/P switchover = 11.92 MPa.
- The shear rate, bilk time = 4.08 sec.

9. Conclusions

The Experiment on High Speed Machining Parameters for Sport Shoe Sole Mold Making Using Aluminum Alloy 5083, 6163 and 7075 has been presented. The objective is to find the best suitable material and machining conditions. The surface roughness (Ra) is acceptable for injection molding is 0.180 µm. The best experiment is investigated that the Al 7075, Al 6163. The spindle speed can be 1100 rpm. or 20000 rpm. together with 500 m/min and 1,000 m/min of cutting speed. The sport mold shoe sole has been created and analyzed by the Mold flow analysis software. The investigations are shown that the Aluminum graded Al 6163 and Al 7075 can be suitably used for the sport sole mold making in or to obtain the acceptable surface roughness without polishing. It can extremely save machining and polishing time.

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