INFLUENCE OF LIQUID NITROGEN COOLING ON THE END MILLING OF ELASTOMERS

Rajesh Nayak
Dept. of Mechanical & Manufacturing Engineering
Manipal Institute of Technology, Manipal, India

Raviraj Shetty
Dept. of Mechanical & Manufacturing Engineering
Manipal Institute of Technology, Manipal, India

Madhukara Nayak
Dept. of Mechanical Engineering
SMVITM, Bantakal, India

Abstract — Maximum products created on elastomers are shaped by some kind of molding and curing process. This paper deals with an innovative method of elastomer machining. End milling experiments were performed with an end milling tool for three speeds, constant feed and depth of cut, and two workpiece temperatures. A Fixture is designed to hold rigidly the elastomer workpiece, because of its relatively low elastic modulus. The objective of these experiments was to better understand the basic machinability of elastomers in dry and cryogenic condition and to examine the influence of cryogenic cooling and circumstances that produce clean and burr-free surfaces in elastomers. From experimental data it can be noticeably seen that increase of cutting force become more significant with higher cutting speeds for cryogenic end milling. Cryogenic end milling presented remarkable improvement in machinability compared to ambient end milling.

Keywords— Elastomers, end milling, dry condition, cryogenic condition. Chip morphology.

I. INTRODUCTION

An elastomer is a material that is capable of recovering from large deformations speedily and forcibly, and can be, or already is, modified to a state in which it is essentially insoluble (but can swell) in a boiling solvent. Elastomers possess many unique material properties like low elastic modulus and high percentage of elongation before fracture, which makes the machining of elastomer a challenge. Elastomer also have very low thermal conductivity. Under cyclic loading, elastomer exhibit hysteresis, which contributes to their energy absorption capability. These unique properties have led many industries to adopt elastomers for a wide range of products including tires, springs, shock isolators, noise and vibration absorbers, seals, corrosion and abrasion protection, and electrical and thermal insulators. At low temperatures, elastomers transform to a brittle, glassy phase, which makes the machining process more efficient. This is beneficial because the workpiece, after being cryogenically cooled, will remain at low temperature for an extended period of time.

Most elastomer parts are manufactured using a molding rather than machining process, to manufacture elastomer parts with complicated shapes, such as tire and foot-wear tread patterns, a set of molds must first be produced. However, there are many disadvantages associated with molding elastomers including high cost, labor-intensive and time consuming process of mold fabrication and the inflexibility of a mold to design changes. For these reasons, machining offers an attractive alternative for manufacturing elastomer components. Very little research on elastomer machining has been conducted because of the complex material response of elastomers and the complexity of the machining process itself. The primary difficulty of machining precision elastomeric parts is due to their low elastic modulus and large deformation characteristics. Early research on elastomer machining was conducted by [4-5]. The benefits of high speed machining using large tool helix and rake angles for manufacturing precision elastomeric parts were demonstrated. The
machining of elastomer using sharp wood working tools was investigated by [6]. With proper selection of end mill geometries, process parameters, and fixture stiffness, clean grooves can be machined in elastomers.

This paper emphasis on influence of liquid nitrogen cooling on the end milling of elastomers. End milling experiments were performed with an end milling cutter on vertical milling machine for three different speeds, constant feed and depth of cut, and two workpiece temperatures. The objective of these experiments was to better understand the basic machinability of elastomers and to identify conditions that produce clean and burr-free surfaces in elastomers.

II. MATERIAL AND PROCESS

A Nitrile rubber specimen matching the dimension as required by the fixture designed to hold the specimen is to be determined before its procurement. The shape of the jaw and size of the milling machine is used to determine the dimensions of the workpiece specimen. According to the shape of the fixture a flat specimen having rectangular cross-section is the ideal specimen. Based on standard ASTM testing [1] the test sample having shore hardness 80, lowest tensile strength 15 N/mm2, elongation at break 200% and glass transition temperature -300c. The width of workpiece specimen can vary between 15-25mm and its length approximately equal to the length of the jaws i.e. around 60-70mm. Thus a workpiece specimen that matches with the dimensions required are then prepared. The dimension specified can be easily clamped between the jaws of the fixture without interfering with the milling operation.

The setup for end milling cutter is according to the size of collet chuck attached to the spindle. The tool with 12 mm diameter, 82 mm long, double-flute, down-cut tungsten carbide tipped tool with straight shank is to be driven by the spindle in a vertical end milling machine. The end mill is attached to the vertical milling machine by means of a collet chuck. The up-cut end milling configuration is widely used in metal machining. If up-cut milling is used, then soft elastomer workpiece will be pulled away from its supporting base. The resulting machined surface will be very rough due to the inadequate support for the workpiece. The elastomer workpiece surrounding the machining area can deform significantly due to machining force. To counteract the deformation, it was found that the down-cut end milling, worked more efficiently for elastomer machining. During the down-cut end milling, chips are pushed into the work-surface and the workpiece is pushed against the fixture [9]. This has provided a better support for the workpiece and alleviates some part fixturing problems. In contrast, up-cut end milling pulls the elastomer material away from the fixture.

The end milling of nitrile rubber under dry and liquid nitrogen cooled condition is carried out on the vertical milling machine. The set up for end milling consists of a fixture plate over which
kistler dynamometer is mounted. Above the dynamometer the fixture holding the workpiece is clamped by means of four allen screws. The allen screws are 3/8 inch in diameter and 2 inch long and ensures that fixture is clamped securely onto the dynamometer. The kistler dynamometer is connected via 1677A5 type connecting cable (with 8 leads) to a 4-channel charge amplifier and to a PC. The PC is the source of digital read out for this dynamometer. Fig 3 shows the connections and set up for kistler dynamometer.

Liquid nitrogen is nitrogen in a liquid state at a very low temperature. The lower temperature of liquid nitrogen when comes in contact with the nitrile rubber specimen freezes it to below zero temperature. Since elastomers have a very low thermal conductivity, hence elastomers are able to retain this phase for a considerable amount of time for machining to take place. Fig 4 shows the liquid nitrogen cooled nitrile rubber specimen. The addition of liquid nitrogen to elastomer specimen induces brittleness to it. Since elastomer is cooled below zero temperature, the particles of elastomers come closer and elastomer becomes rigid. The mechanism of machinability depends upon the relative hardness of the cutting tool and the workpiece.

The X-axis coincides with the feed direction. The Z-axis is along the rotating axis of the tool which is perpendicular to and pointing outward from the flat surface of elastomer. Fx, Fy, and Fz are three end milling force components acting on the workpiece from the rotating tool. The Fx should generally be negative because of the tool feed direction. Due to the rotational direction of the tool, the Fy should be mostly positive. Since the tool pushes the workpiece in the positive Z direction, Fz should remain positive [7].

III. RESULTS & DISCUSSION

The end milling of elastomer is performed under dry and liquid nitrogen cooled condition by varying the spindle speed and keeping the feed rate and depth of cut constant. This will enable to deduce a relationship between the spindle speed and the cutting forces. Also the above machining condition will give a relationship between the cutting forces associated with dry and liquid nitrogen cooled workpiece end milling. The curves for cutting forces are obtained as a function of time as shown in fig. 9-14. The cutting force curve has lot of peaks and valleys. The curve does not give an absolute value for the force, rather it gives an average value. The above curves shows
that as spindle speed increases there is a corresponding decrease in the cutting force. The curve also shows that the cutting forces encountered in case of cryogenic milling is higher as compared to dry milling of elastomer.

The change in force values with different spindle speeds under dry end milling is shown in Fig.9-11. The data shows that all three force decreases with an increase in cutting speed. For increase in Spindle speed from 450rpm to 900 rpm the decrease in feed force recorded is ranges from -622.4N to -641.9 N. A decrease from 105.4N to 95.78N is observed in cutting force. Similarly the thrust force also decreases from 105.2 N to 88.18N with increase in spindle speed. The overall decrease in forces is less than 20%.

The recorded force values with different spindle speeds under liquid nitrogen cooling in end milling is shown in Fig.12-14. The variation shows that all three force decreases with an increase in cutting speed. For increase in Spindle speed from 450rpm to 900 rpm the decrease in feed force recorded is ranges from -633.3N to -651.0N. A decrease from 130.8N to 115.7N is observed in cutting force. Similarly the thrust force also decreases from 132.2 N to 120.9N with increase in spindle speed. The overall decrease in forces is less than 20%.

Fig. 15-17 shows the comparison of average forces obtained in dry and LN2 milling for three spindle speeds. As shown in Fig.15 to17 larger forces are produced during cryogenic cutting. The increase of cutting force becomes more significant
with higher spindle speeds for cryogenic cutting. This is due to a larger modulus of rubber and increased rigidity of rubber at lower temperatures leading to less workpiece material flow underneath the tool clearance surface which is very much beneficial in maintaining cutting stability and achieving a good machined surface finish. In contrast, under ambient temperatures rubber is more flexible and easier to flow beneath the tool during cutting, which would lead to lower cutting force.

It is known from the theory of metal cutting that an examination of machined chips provides the cheapest and the most effective way of understanding the machining characteristics of a material. Chips were collected and analyzed after the milling tests. Fig.18 and Fig.19 shows various SEM images of chip types that correspond to the relative machined surfaces under dry and LN2 milling conditions.

IV. CONCLUSION

- In this study the end milling of elastomers was investigated by the use of an end mill cutter under dry and LN2 cooled conditions.
- During the data analysis it was observed that the value of cutting forces decreases with an increase in Spindle speed both in dry and liquid nitrogen cooling.
- Increase in forces in LN2 end milling in within the range of 10% compare to dry end milling.
- SEM Images obtained shows that LN2 end milling produces continuous chips compare to dry end milling which leads to better surface finish.

V. REFERENCES