CRYOGENIC CNC MILLING OF NEOPRENE RUBBER FOR RAPID PROTOTYPING

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1. Introduction

Elastomer parts are widely used in engineering, but prototype production is difficult because molding methods require dedicated tooling and high cost. For low-volume manufacturing, CNC machining becomes a more flexible alternative. However, room-temperature machining of rubber is unstable because the material easily deforms under cutting forces. Earlier studies show that cooling the elastomer and using sharp down-cut tools significantly improve machinability. Since neoprene has a glass-transition temperature around −42°C, cryogenic milling below this level is a practical solution for temporary stiffening of the material [1].

2. Materials and Methods

The material used in this work was neoprene rubber. To enable machining, the samples were frozen in an alcohol-based cooling medium with a temperature close to −100°C. During cutting, the rubber temperature was kept approximately between −60 and −80°C, which is below the glass-transition range of neoprene. Published research on elastomer milling reports good results with double-flute down-cut carbide end mills under moderate spindle speed, feed, and depth of cut conditions [2]. Based on this approach, similar soft-rubber-compatible CNC parameters were used in this study. Machining was performed using a 2-flute down-cut carbide end mill (3 mm diameter) at a spindle speed of 10,000 rpm and a feed rate of 350 mm/min. The axial depth of cut was set to 0.5 mm, the radial step-over to 0.8 mm, and the plunge rate to 120 mm/min. These parameters were chosen to provide stable cutting conditions for cryogenically cooled neoprene while minimizing edge damage, elastic recovery, and thermal softening. Two machining strategies were investigated: conventional milling and climb milling.

3. Results and Discussion

In conventional milling, the cutter rotates against the feed direction, while in climb milling it rotates with the feed. Climb milling is generally preferred on rigid CNC machines because it often improves finish and reduces rubbing. However, for soft and compliant materials, conventional milling may provide more stable tool engagement and reduce the tendency of the cutter to disturb the workpiece.

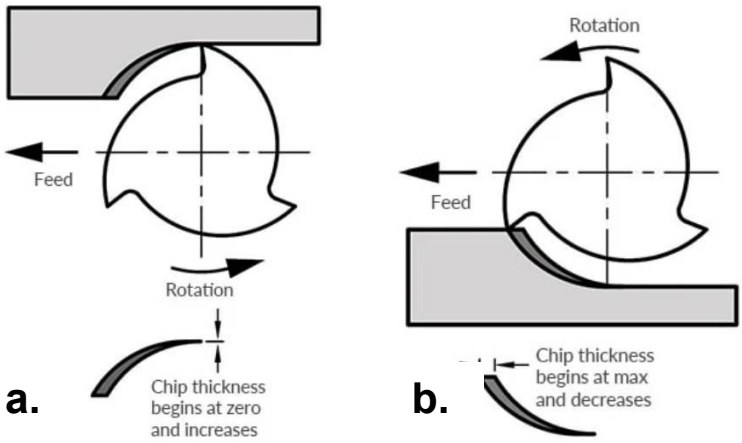


Figure 1. a. Conventional milling, b. Climb milling

The experiments showed that cryogenic cooling made neoprene sufficiently rigid for CNC milling and reduced excessive deformation during material removal. Both milling strategies were feasible, but conventional milling gave better results than climb milling under the selected conditions. It provided more stable cutting and better edge quality for the frozen neoprene samples. These results confirm that cryogenic machining can be used as a practical prototype manufacturing method for elastomer parts without mold-based tooling.

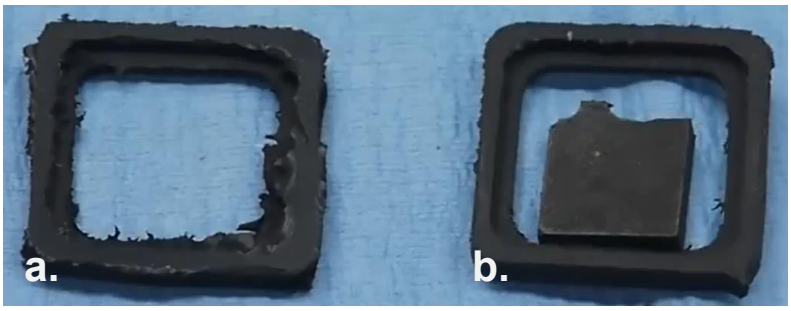


Figure 2. a. Conventional milling result, b. Climb milling result

4. Conclusion

This approach can be recommended as an alternative to casting and injection molding when low tooling cost, fast iteration, and prototype flexibility are required.

References

1. J. Luo, *Machining of Elastomers*, PhD Dissertation, University of Michigan, 2005.
2. V.G. Dhokia, S.T. Newman, P. Crabtree, M.P. Ansell, “A process control system for cryogenic CNC elastomer machining,” *Robotics and Computer-Integrated Manufacturing*, 2011.