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Effect of magnetorheological fluid on tool wear during hard turning with minimal fluid application

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ABSTRACT

Tool wear is a very complex phenomenon which can lead to machine down time, product rejects and can also cause problems to personnel. The present investigation aims at developing a magnetorheological fluid setup that can be attached to the tool holder for reducing tool wear during hard turning with minimal fluid application. The magnetorheological fluid acts as a viscoelastic spring with non-linear vibration characteristics that are controlled by parameters like the viscosity index of the fluid medium, shape of the plunger, current through the coil and size of the ferromagnetic particles. Cutting experiments were conducted to arrive at a set of magnetorheological fluid parameters that can offer better damping characteristics to minimize tool wear and promoting better cutting performance during turning of AISI 4340 steel of 46 HRC with minimal fluid application using hard metal insert with sculptured rake face. From the results, it was observed that the presence of magnetorheological fluid setup during hard turning with minimal fluid application attached to the tool holder reduces tool wear and brought forth better cutting performance. Commercialization of this idea is sure to benefit the metal cutting industry.

1. Introduction

Conventionally when cylindrical parts requiring high hardness as functional requirement are to be machined, the work piece is turned to the near net shape, hardened to the required hardness and ground to the final dimension. This lengthy process cycle can be avoided by hard turning which is intended to replace or limit traditional grinding operations [1]. But hard turning involves very large quantities of cutting fluid. Procurement, storage and disposal of cutting fluid involve expenses and it has to comply with environmental legislation such as OSHA as well. Pure dry turning is a solution to this problem as it does not require cutting fluid at all. But pure dry turning requires Ultra Hard cutting tools and extremely rigid machine tools and it is difficult to implement in the existing

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shop floor as the machine tools may not be rigid enough to support hard turning. In this context, turning with minimal fluid application is a feasible alternative where in, extremely small quantities of cutting fluid with high velocity are applied at the critical contact zones, in the form of a pulsing slug so that for all practical purposes it resembles pure dry turning and at the same time, free from all the problems related to large scale use of cutting fluid as in conventional wet turning.

During minimal fluid application, extremely small quantities (about 2 ml/min) of cutting fluids are applied at critical zones in the form of a high velocity pulsed jet so that fluid particles reach the tool chip interface and provide enhanced rake face lubrication. Varadarajan et al. [2] observed that during minimal fluid application, the overall cutting performance was superior to that during dry turning and conventional wet turning.

In hard turning with minimal fluid application, tool wear becomes an important parameter affecting surface roughness of finished parts [3]. Tool wear is a very complex phenomenon which can lead to machine down time, product rejects and can also cause problems to personnel. The life of a tool can come to an end in two major ways. The first one is the progressive tool wear as a result of the wearing away of certain regions of the face and flank of the cutting tool. This leads to the gradual deviation of the surface finish from the tolerance limit as the tool wear progresses and finally necessitates the replacement of the cutting tool. The second mode is the catastrophic tool failure bringing the life of the tool to a premature end. The present study addresses the progressive type of tool wear. In metal cutting, progressive tool wear occurs in three main forms namely adhesion wear, abrasion wear and diffusion wear. Each wear form has its own characteristic symptoms. Variation of cutting force can carry information on adhesive and breakage type of tool wear. Excessive tool vibration is an index of abrasive type of tool wear and it will increase the tool wear and cause poor surface finish during machining [4]. Diffusion and crater type of tool wear are accompanied by excessive cutting temperature and the rate of diffusion increases exponentially with increase in temperature. High cutting force, excessive cutting temperature and increase in tool vibration are indications of progressive tool wear [5].

In actual cutting conditions, the vibration of the cutting tool depends on the tool wear and increases as the tool wear progresses [6]. The tool will be sharp in the beginning and slowly loses its sharpness as the cutting process progresses. Hence the amplitude of tool vibration will be less during the initial stage which increases slowly as the tool wear progresses and becomes very high when the tool is nearing the end of its life. Hence comparatively less damping is needed in the beginning and more damping capability is desirable when the tool is nearing the end of its life. Hence for a comprehensive control of surface finish, a damper in which the damping capability can be varied in line with the magnitude of tool wear will be more desirable than a damper with a fixed damping capability. In such a system, the damping capability will be varied by adjusting some controlling parameters of the damper as needed by the magnitude of the tool wear.

Spencer et al. [7] was the first among the scientists who tested magnetorheological fluid dampers to improve cutting performance during machining. J.D. Carlson and J.L. Sproston [8] investigated the properties and applications of commercially available magnetorheological fluids and it was observed that the magnetorheological fluids can operate at temperatures from −40 to 150 °C, with only slight variation in the yield stress. Also this rheological fluid damper was found to be more effective than the conventional viscous damper [9]. Wang and Fei [10] tried to suppress chatter in boring bar using an electro rheological fluid damper and developed an on line chatter detection and control system. Lord Corporation [11] developed magnetorheological fluid shock absorbers for automobiles and it was observed that such shock absorbers can respond instantly and can control varying levels of vibration, shock and motions. Genc and Phule [12] observed that the properties of the magnetorheological fluids can be varied by varying the parameters associated with magnetorheological fluids like volume, particle size fraction of solids, etc. Also it was reported that using MR fluid dampers, chatter could be suppressed more effectively by adjusting the damping and natural frequency of the system in boring bar [13]. Sathianarayanan et al. [14] investigated the suppression of chatter in boring tools using MR damper and observed that MR damper reduces the possibility of chatter and improves the stability of boring operation.

In the present investigation, an attempt was made to develop a magnetorheological fluid system which can be easily attached to the tool holder for reducing tool wear and improving cutting performance during hard turning with minimal fluid application. When an electric field is applied to the magnetorheological fluid, it becomes a semisolid and behaves as a viscoelastic spring with non-linear vibration characteristics. This transition is reversible and takes place in a few milliseconds. Cutting experiments were conducted to arrive at the optimum viscosity of the fluid, shape of the plunger and the magnitude of the current passing through the magnetizing coil that can offer a damping characteristics which will minimize tool wear and promote better cutting performance during turning of AISI 4340 steel of 46 HRC with minimal fluid application using hard metal insert with sculptured rake face. It was observed that the presence of magnetorheological fluid system attached to the tool holder reduces tool wear and improves cutting performance. The scheme which is specifically developed for hard turning with minimal fluid application may be extended to improve cutting performance during normal turning operations as well.

2. Selection of work material

AISI 4340 steel was selected as a work material which is widely used in die making, automobile and allied industries [2]. Its applications include aircraft engine mounts, propeller shafts, connecting rods, gear shafts, crane shafts, heavy forgings such as rotor shafts, discs, welded tubing applications, etc. It is a through hardenable medium alloy steel that can be hardened to 46HRc and is known for its toughness, tensile strength and fatigue strength and is less costly compared to high alloy steels. Considering its wide range of application in the industry this grade of steel was considered as the work material in the present investigation. Bars of 80 mm diameter and 380 mm length were used in the present investigation. The chemical