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Investigation on the effect of cooling of the tool using heat pipe during hard turning with minimal fluid application

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ABSTRACT

Hard turning with minimal fluid application is a recently developed technique to alleviate the problem associated with cutting fluid. During this process, very small quantity of cutting fluid is applied as a narrow high velocity pulsing jet at the cutting zone. As the quantity of cutting fluid is very small, some auxiliary cooling of tool using heat pipe was attempted in the present work to enhance heat dissipation and thus improving cutting performance. Heat pipe was installed in vertical position in contact with the tool for extracting more heat from the tool. The influence of heat pipe cooling of tool on the cutting performance was analyzed by Taguchi's design of experiments. It was observed that the use of heat pipe in minimal fluid application reduced cutting temperature and tool wear to a maximum of 22% and 15%, respectively, in comparison with conventional hard turning with minimal fluid application without the aid of heat pipe. It appears that heat pipe can be successively employed as a mean of cooling the tool during hard turning with minimal fluid application.

1. Introduction

Hard turning process inherently generates high cutting temperature due to high hardness of the work piece and the existence of high friction at the tool–chip interface and the tool–work interface. The tool life in the hard turning is commonly improved by supplying large quantity of cutting fluid. However, the introduction of cutting fluid brings forth health and safety concerns [1,2]. In addition, the cost of procurement, storage and disposal of cutting fluids is several times higher than tool cost [3]. Due to the technological innovations such as ultra-hard tool materials, new tool coatings material, and optimized tool geometry, machining without cutting fluid called dry turning is developed. However in dry turning operations, the friction and adhesion between chip and tool tend to be higher which causes higher temperatures, higher wear rates and consequently shorter tool lives. Further, dry turning needs extremely rigid machine tool which is difficult to implement on the shop floor with the existing machine tools. All these problems related to turning with conventional flood cooling and pure dry turning lead to research on machining with minimal fluid application [4] as an alternative.

Machining with minimal fluid application (MFA) is a technique to minimize the use of cutting fluid on the shop floor. In this technique, extremely small (2 to 5 ml) quantities of proprietary cutting fluid are applied at the critical zones as a pulsed jet. It is reported that the frictional forces between two sliding surfaces can be reduced by rapidly fluctuating the width of the lubricant filled gap separating them [5]. This principle was used for developing the minimal cutting fluid application system for minimizing the consumption of cutting fluid in machining. In MFA, fluctuation of width of lubrication that is filled in the gap between the tool rake face, and the chip is achieved with a high velocity narrow pulsing jet. It is reported [6–8] that this new technique not only reduced the usage of cutting fluid drastically but offered better cutting performance as well when compared to wet turning.

In minimal fluid application, extremely small quantity of cutting fluid in the order of 2 ml/min is available for the dual purpose of cooling and lubrication. Extreme temperature conditions that exist near the root of the chip may cause the thermal degradation of the cutting fluid. Due to this, cutting fluid loses its lubrication property and fails to reduce frictional condition at the cutting zone. If some auxiliary cooling means is designed to cool the tool would avoid the degradation of cutting fluid and improve the cutting performance. Heat pipes can be successfully used for removing heat in many applications as found in the literatures. Use of heat pipe in machining for cooling the tool can reduce the amount of cutting fluid used and the associated environmental pollution. The review

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of literatures clearly revealed that, no study has been made in relation to the application of heat pipe in the area of machining with minimal fluid application. Hence, in order to achieve the effective cooling of the tool during machining with minimal fluid application, use of heat pipe is explored in the present work.

2. Literature review

Heat pipe is a heat transfer device with a very high thermal conductance. It is used to transport heat from one location to another without the need for an external power supply by diffusion [9]. A heat pipe consists of an evacuated container sealed at ends, a wick structure, and a small amount of working fluid in equilibrium with its own vapor. A heat pipe has three sections namely evaporator section, adiabatic (transport) section, and condenser section. The external heat load on the evaporator section causes the working fluid to vaporize. The resulting vapor pressure drives the vapor through the adiabatic section to the condenser section. In the adiabatic section, no heat is absorbed or rejected. The condensing section condenses the vapor and the latent heat of vaporization of the working fluid is rejected into the atmosphere. The condensed working fluid is then pumped back by capillary pressure generated in the wick structure. Transport of heat can be continuous as long as there is enough heat input to the evaporator section so that sufficient capillary pressure is generated to drive the condensed liquid back to the evaporator. Large quantities of heat can be transported through a small cross-sectional area over a considerable distance with no additional power input to the system using heat pipe when compared to other conventional methods of heat transfer.

Heat pipes are used for cooling purposes in a wide range of applications. Recently, it found its application in the field of manufacturing to control the process temperatures in die-casting, injection molding and metal machining. Application of heat pipe in metal machining as an alternative to conventional method of removing heat from the cutting zone is an emerging area of interest among researchers. Cooling of cutting tool reduces cutting temperature and improves the tool life by reducing tool wear [10–13].

Noorul Hag et al. [14] investigated the effect of parameters such as diameter of heat pipe, length of heat pipe, magnitude of vacuum in the heat pipe and the material used for making heat pipe on cutting performance. Heat transfer efficiency of heat pipe during hard turning of engine crank pin material using mixed alumina insert was studied. A set of heat pipe parameters for optimum performance were arrived at by performing a nine run experiment. There was considerable improvement in tool life when a 400 mm Hg vacuum was maintained in a heat pipe made of brass having length 40 mm and diameter 7 mm was used.

Liang et al. [15] studied the effect of heat pipe in reducing the tool–chip interface temperature of the cutter with a flat heat pipe attached on the rake face of insert in dry turning. The results showed that the tool–chip interface temperature could be reduced effectively for the cutter with heat pipe cooling and the reduction in temperature is found to be more at the higher cutting speed. Zhu et al. [16] experimentally verified the feasibility and effectiveness of heat-pipe cooling in end-milling operations. The result demonstrated that use of heat pipe cooling reduced the tool wear and prolonged the tool life of end mill cutter.

Zhu et al. [17] made a numerical study in order to investigate the effect of heat pipe cooling in drilling operations by predicting the thermal, structural static and dynamic characteristics of the tool. The numerical simulation indicated that heat pipe assisted drilling reduced the peak temperature and stress on the tool tip when compared to dry drilling. Liang et al. [18] estimated the amount of heat flowed into the turning tool and that carried away by the heat pipe. It is found that the presence of heat pipe increased the amount of heat flowing into the tool and also increased the amount of heat dissipation from the tool which helped in reducing of temperature at tool chip interface.

Review of literatures indicated that cutting performance can be improved by introducing heat pipes for removal of heat from the cutting tools. Heat pipe assisted cooling system can reduce or eliminate the use of cutting fluids and the associated environmental pollution. Moreover, the above literature clearly revealed that no study has been made related to the application of heat pipe in the area of machining with minimal fluid application.

In the present research work, an attempt was made to investigate the applicability of heat pipes in cooling the cutting tool during hard turning with minimal fluid application. The objective is to investigate the effect of heat pipe cooling of tool on cutting force, tool wear, surface finish and cutting temperature during turning of hardened AISI 4340 steel with minimal fluid application using multicoated carbide insert.

3. Experimental procedures

Cutting experiments were conducted on a Kirloskar Turn master-35 lathe to study the influence of heat pipe assisted cooling of cutting tool on cutting performance during minimal fluid application. AISI 4340 steel with hardness of 45 HRC was used as work material. Cutting tool consisted of tungsten carbide inserts with sculptured rake face with a specification SNMG 120408 and a tool holder PSBNR 2525M12 by Taegutec were used in the experiments. Since the quantity of cutting fluid used is extremely small, a specially formulated cutting fluid was employed in this investigation. The formulation consisted of petroleum sulfonate (15% by weight), ethylene glycol (1% by weight), oleic acid (3% by weight), triethanol amine (3% by weight), alcohol ethoxylate (3% by weight) and paraffinic mineral oil (rest) [19,20]. It acted as oil in water emulsion. Petroleum sulfonate acts as an emulsifier, rust inhibitor, surfactant and EP agent. Ethylene glycol resists freezing due to its low freezing point and acts as a coupling agent to increase the stability of the emulsion. Oleic acid is used as an emulsifying or solubilizing agent in aerosol products. It serves as an agent for improving the lubricity of the cutting fluid. Triethaol Amine is used to provide the alkalinity needed to protect the work against rusting and it acts as an antioxidant. It also controls the evaporation rate of water in cutting fluid. Alcohol ethoxylates possess greater resistance to water hardness than many other surfactants. Commercially available paraffinic mineral oil was used as base.

Cutting fluid was applied at the tool work interface with the help of a minimal fluid applicator. Minimum fluid applicator shown in Fig. 1 can deliver very small quantity of cutting fluid in the form of high velocity pulsing jet and has the facility to vary the

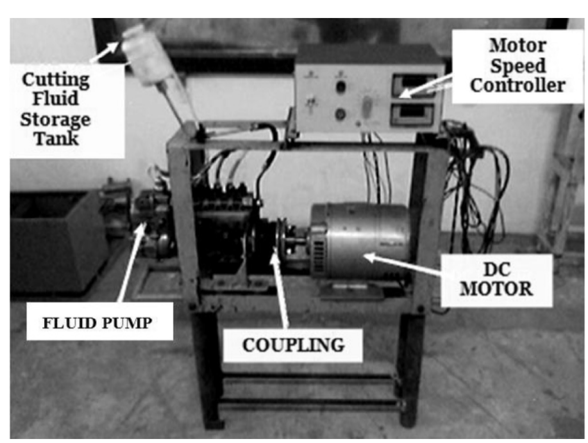

Fig. 1. Minimal fluid application system.

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