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System of high-performance cutting with enhanced combined effect of cooling and lubrication medium based on Ranque-Hilsch Effect

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Abstract

Presents the results of the study of the main factors for improvement of the efficiency of high-performance cutting of structural steels. It has been revealed that such improvement should be implemented on the basis of simultaneous enhancement of cooling and lubrication medium (CLM). It is shown that the standard methods of supplying CLM to cutting area or use of air ionized by corona discharge as process medium are not able to effectively cool cutting area during blade cutting because of balance of endothermic and exothermic reactions. The study has considered the possibility of enhancement of CLM on the basis of Ranque-Hilsch Effect, the use of which during cooling of air flow in vortex tube allows overcoming the dew point, resulting thereby in intense air humidification and substantial enhancement of lubricating effect of process medium. It has been found out that cumulative effect of efficient cooling and enhancement of lubricity of ionized air process medium contributes to improvement of the basic characteristics of cutting process, improves tool life and significantly increases the efficiency of high-performance cutting.

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Keywords: Cooling; Machining; Ranque-Hilsch Effect; Cutting tool; Cutting

Introduction

Tool performance improvement in metal cutting is largely determined by the efficiency of cooling and lubrication media (CLM) used, which main functions are primarily to initiate lubricating and cooling effects. These two effects are interdependent. Improvement of tribological conditions of contact area through formation of separating lubricant films on the tribocoupling surfaces of the tool material and the material being machined results in reduction of frictional forces between them, i.e., in reduction of heat generation. However, in most cases, the heat is not dominant. The main amount of heat is generated as a result of the deformation processes that accompany the process of fracture (chip separation) of the metal being machined during cutting.

Generated heat should be removed, since elevated temperatures become a factor contributing to the development of adhesive interactions between tribocoupling materials in the contact area. This will inevitably result in the increase of the power characteristics of the cutting process and, consequently, in the increase in the amount of the heat generated. Thus, the great attention should be paid to the enhancement of the cooling function of CLM, especially in cases when the technological medium is not a water-soluble composition. The effective heat removal from the contact area reduces the thermomechanical load on the working surfaces of the tool and thereby increases tool life. Besides, the use of nanoscale multilayer composite coatings can further reduce generation of heat during cutting process and create favourable distribution of the heat flows in a cutting wedge [1-5]. The conducted research [1-6] for the study of the thermal state of the cutting wedge of the tool, in which surfaces the solid lubricating structures are pre-formed and represented by iron diiodide, as well as of the

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cutters with multilayer composite coatings, results in the following conclusions. It has been found out that the lubricant and the multilayer composite coatings have an effective impact on the reduction of the size of the temperature fields; however, the dominant role in heat removal is played by additional refrigerant coolants introduced (Fig. 1).

Despite the fact that some sources treat the use of ionized air without any preliminary preparation as CLM as "dry electrostatic cooling" (DEC) [7, 8], the conducted studies [9, 10] have not revealed any significant change in cooling rate and increase of performance due to the change in the thermal strain state of tool contact areas. Moreover, the thermodynamic analysis of chemical reactions in ion flow and contact area has shown that the cooling effect of DEC is overlapped by exothermic reactions between components of ionized air, as well as by reactions of metal oxidation [11].

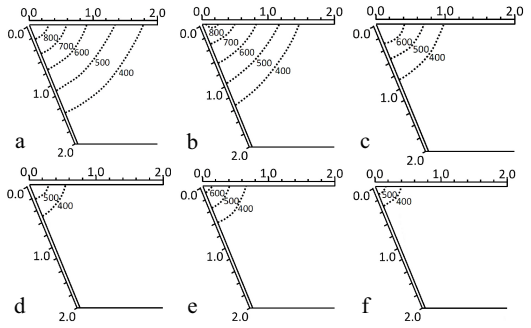

Fig. 1. Effect of CLM composition on value and distribution of temperature fields in cutting wedge of cutters during free turning of Grade2 Ti-alloy: a – without lubrication, without cooling; b – with lubrication, without cooling; c – without lubrication, with cooling by distilled water; d – with lubrication and cooling by distilled water; e – without lubrication, with R-113 Freon cooling; f – with lubrication and R-113 Freon cooling. V = 0.46 m/s

Methodology

The Ranque-Hilsch (RH) effect was generated with the use of specially prepared vortex tubes RH vortex tubes, the effect of which is based on energy "separation" of gas flows. Such redistribution of energy between gas atoms inside the vortex tube cools the central portion of the gas flow and transfers heat (energy) of its peripheral portion. As a result, one side of the vortex tube releases chilled air, and another heated air. Meanwhile, the vortex tube has no moving parts, it is able to operate without interruptions, it is easy to use, and it reduces the outlet temperature by 10-50 degrees. However, despite the fact that the RH effect is described in sufficient number of both theoretical and experimental papers, the seemingly simple effect is a complex theoretical problem of gas dynamics, and at present, there is no single mathematical formalism to describe it. According to [12], the cooling effect is defined as the difference of temperatures between incoming and chilled air, i.e., $\Delta T = T0 - Tx$. The presented data show that the effect of cooling (Fig. 2,3) in the case of the maximum negative temperature (-14ºC at 7.5 *atm*) reaches 36 degrees. Meanwhile, it is found out that when inlet pressure increases from 5 up to 7.5 *atm*, the cooling effect decreases (from 30 down to 36 degrees).

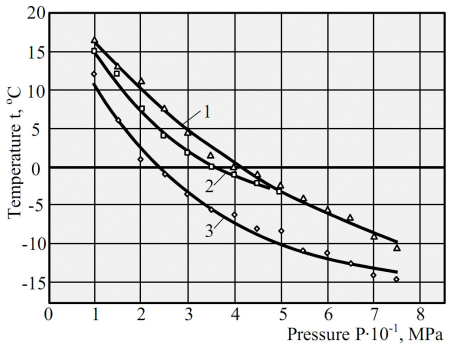

Fig. 2. Relation between chilled air temperature and pressure on tube inlet. Vortex tube diameter: 1- 6 mm; 2 – 10 mm; 3- 5 mm

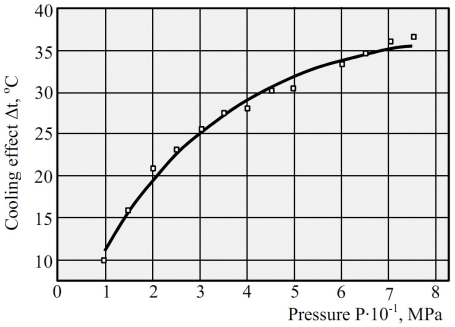

Fig. 3. Effect of cooling of vortex tube with diameter of 5 mm depending on inlet pressure

Negative temperatures of air flow at the outlet of the vortex tube inevitably result in the separation of moisture in the chilled air, since in normal conditions, dew point boundaries are observed at a higher temperature. Furthermore, it is known that dew point depends on temperature, humidity and pressure of the gas mixture used, and the higher the pressure is, the higher the temperature of the dew point of the compressed air is.

According to the data of [13], for the experimental conditions (air temperature in the laboratory: Td = 20°C, humidity F = 67%) at pressure of 0.4 MPa, dew point Td = 40°C, which is two times higher than the temperature inside the laboratory and is at least by 40° higher than the temperature of the air leaving the vortex tube. Given the fact that the pressure in the vortex tube decreases because of its structural characteristics (output of warm air), and the dew point temperature in this case is achieved at the inlet pressure of 0.2 MPa. Thus, it can be noted that at the outlet of the RH vortex tube, the composition of chilled air contains micro- and nanodozes of water, since the dew point is overcome. Consequently, the overall effect of the vortex tube in actual cutting will be a combination of the two processes: on the one hand, as a result of the direct cooling effect, and on the other hand, as a result of the reduction of heat generation in cutting area, due to the formation on contact areas of separating oxide films, which reduce friction between tribocoupling surfaces. The studies [14], shown in Fig. 4, justify the efficiency of action of water vapour in the air used as CLM.

The studies of the influence of the RH cooling effect on