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RESEARCH ON THE INFLUENCE OF COOLING AND LUBRICATION ON THE SURFACE LAYER SELECTED PROPERTIES

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Abstract

The paper presents the structure and selected results of the BW 13/2007 research conducted in the Production Engineering Department. It describes the conditions and application range of dry and MQL cutting, as well as the results of an analysis into the machined surface geometrical structure, cutting forces and residual stresses in the surface layer.

Keywords*: turning, dry cutting, minimum quantity lubrication, MQL, surface layer, cutting force, residual stresses*

1. Introduction

Within the BW 13/2007 research program – ECOLOGY-ORIENTED SURFACE SHAPING ENGINEERING FOR SPECIFIC SERVICEABLE FEATURES – the Department of Production Engineering conducts research on the physical nature and conditions of cutting processes and their influence on technological and operational characteristics of the machined surfaces. The predominant field in the ecology-oriented surface shaping is the author's research on the influence of cooling and lubrication in the cutting zone on the machined surface layer properties in turning steel 45 and austenitic stainless steel 00H17N14M2.

2. Conditions and range of application of dry and MQL cutting

The increasing awareness of the negative impacts of production processes has led in many countries to legislative regulations limiting or eliminating some of the manufacturing processes. This has caused an increase in production costs related mainly to the prevention and elimination of the negative effects. The current pro-ecology actions necessitate a search for new solutions to minimize and, eventually, to eliminate the harmful by-products of production processes. It can be achieved by improving the currently employed technologies and elaborating new ones which will conform to rigid environment protection standards. Among the production methods, machining has found its way into many branches of industry. Because of its huge share in manufacturing processes and a negative impact on the environment, it has also attracted the attention of many scientific and industrial centers. An important factor in the cutting process, which often positively affects the quality of the machined elements, tool life and production costs, is the cutting fluid. Critical as cutting fluids are for machining processes, they also pose a substantial threat to the direct surrounding of the workplace, health and safety of machine operators as well as to the natural environment (air, water, soil) [3, 4]. Hence the effort aimed at eliminating (dry cutting) or limiting (minimum quantity cooling/lubrication – MQC/MQL cutting) their use [1, 2]. Conditions underlying wide interest in eco-friendly manufacture and its resulting advantages are shown in Fig. 1.

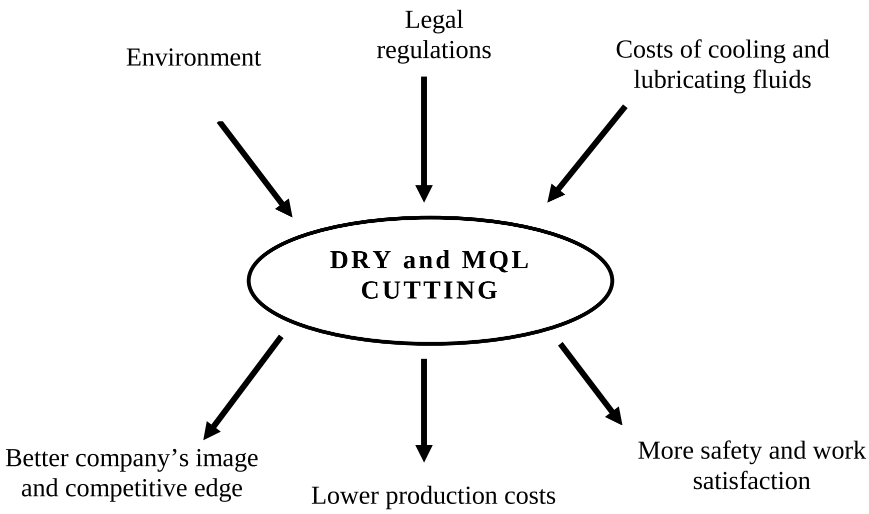


Fig. 1. Conditions and advantages of dry and MQL cutting [3]

The primary objective of cutting fluids in the cutting process is cooling and lubricating the cutting zone, which diminishes friction between the adjoining surfaces and facilitates the removal of chips from the cutting area (fig. 2). The elimination of the cooling and lubricating fluid (CLF) in dry cutting causes that neither cooling nor lubrication or removal of chips from the machine working space is performed. This seems to be the basic drawback of dry cutting, which also leads to undesired changes in cutting conditions. Lack of cooling means a higher cutting temperature, shorter tool life, warped surface texture with greater residual stresses, lesser dimensional and shape accuracy. It also results in degraded surface roughness and difficulty in removing hot chips and measuring the machined object. From the ecological point of view, without the flushing action of the CLF, the air, the machine and its immediate surrounding become polluted with metal dust and chippings. All these come about if there is no CLF, making the dry cutting method difficult for industrial application._As long as there is no substitute for CLFs to effectively perform their functions, dry cutting cannot be successfully implemented [9, 10, 11].

The complete elimination of CLF is also impossible in the case of certain machined materials or machining methods because it leads to degraded quality, lower machining productivity and inferior conditions of chip disposal.

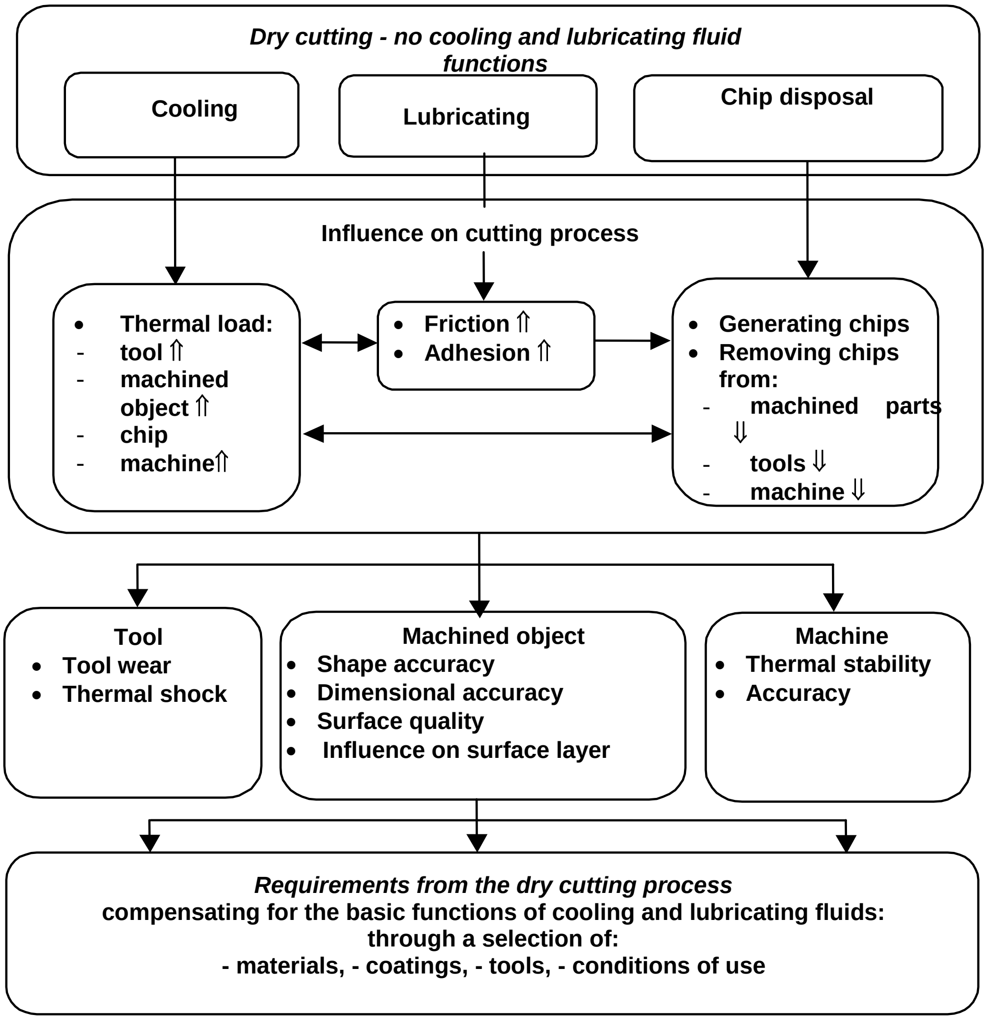


Fig. 2. Effects and requirements of dry and MQL cutting [9]

When dry cutting is not an option because of its drawbacks and difficult cutting conditions, minimum quantity cooling and lubrication may be an alternative. It helps to decrease production costs by 10 – 50% as well as minimizing environmental and health hazards. Minimum quantity cooling and lubrication (MQL) cutting or minimum quantity fluid (MQF) cutting, also referred to as quasi-dry cutting, can be characterized by a small quantity of cooling and lubricating fluid supplied to the cutting zone – the amount usually does not exceed 50ml/h [2, 11].
Despite the described issues with dry and MQL cutting, they are used especially in high volume and mass production (Table 1).

Tab. 1. Application range of dry and MQL cutting [11]

Material / Process	Aluminum		Steel		Cast iron
	Cast alloys	Wrought alloys	High alloyed steel	Construction steel	
drilling	MQL	MQL	MQL	MQL	MQL
reaming	MQL	MQL	MQL	MQL	MQL
tapping	MQL	MQL	MQL	MQL	MQL
deep hole drilling	MQL	MQL	MQL	MQL	MQL
milling	MQL/dry	MQL	dry	dry	dry
turning	MQL/dry	MQL/dry	dry	dry	dry
gear milling			dry	dry	dry dry
sawing	MQL	MQL	MQL	MQL	MQL
broaching			MQL	MQL/dry	dry

3. Research and results

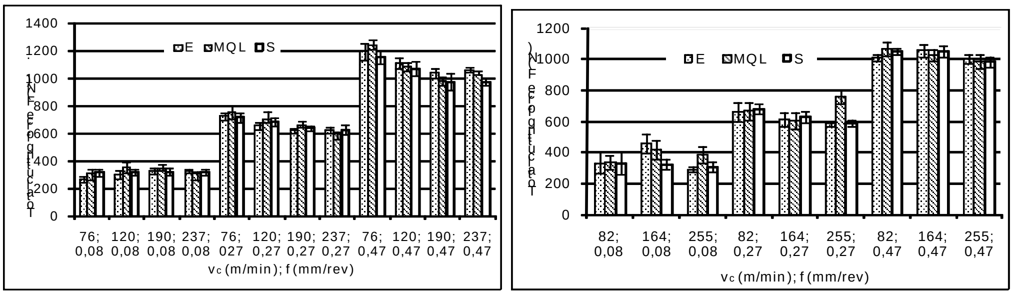
The conducted research into the formation of surface layer in dry and MQL turning covers the areas presented in Fig. 3.

The results of the research into cutting force in turning steel 45 and stainless steel 00H17N14M2 have shown that eliminating or limiting the application of the cutting fluid in the cutting zone does not cause any substantial change in the value of the total cutting force (Fig. 4). However, the cutting force's components: F_c, F_f and F_p are more affected. The influence of the cooling and lubrication mode largely depends on the employed cutting parameters: cutting speed and feed rate [5].

The analyses of the machined surface texture parameters shown in Fig. 5 and 6 have confirmed a major influence of the cooling and lubrication mode on the analyzed surface characteristics of the geometrical structure in turning steel 45 and 00H17N14M2. It also needs to be added that this influence was dependent on the employed cutting parameters [6, 7]. Dry and MQL turning of steel 00H17N14M2 generated smaller surface roughness and waviness than turning with a cutting emulsion supplied to the cutting zone. Depending on the employed cutting parameters, the MQL method gave a smaller roughness and waviness of the machined surface, compared to dry and emulsion cutting. The cooling and lubrication mode in the cutting zone substantially influence the bearing ratio of the roughness profile at slow cutting speeds. The influence diminished at faster speeds. An unfavorable change appeared with the increase of feed rate: the bearing ratio of the roughness profile decreased.

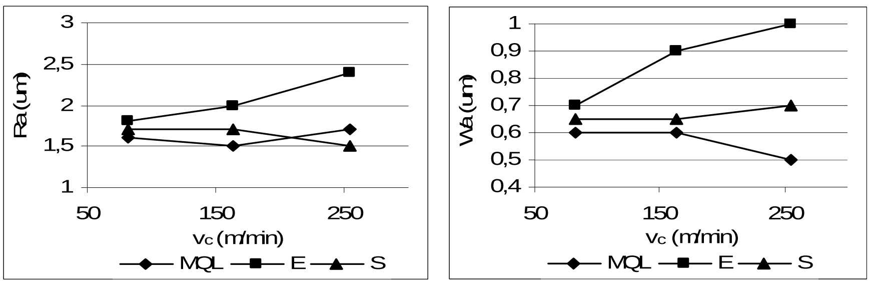
Dry and MQL turning development state	• Significance of cooling and lubrication in cutting process • Determinants of dry and MQL machining • Technological conditions for dry and MQL turning
Physical aspects of surface layer forming process	• Chip forming and shape • Cutting force • Cutting temperature • Tool wear
Surface layer properties	• Surface texture- roughness, waviness, bearing ratio • Surface layer thickness, hardness • Metallographic structure • Residual stresses

Fig. 3. Surface layer research structure



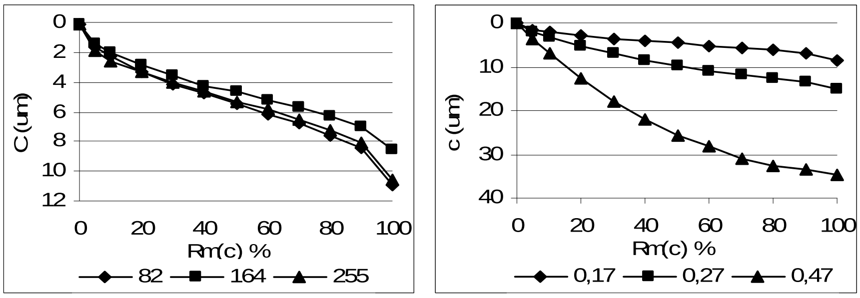
(a) (b)

Fig. 4. The influence of the cooling and lubrication mode, the cutting speed and feed rate on the total cutting force, a – steel 45, b – steel 00H17N14M2 [5]



(a) (b)

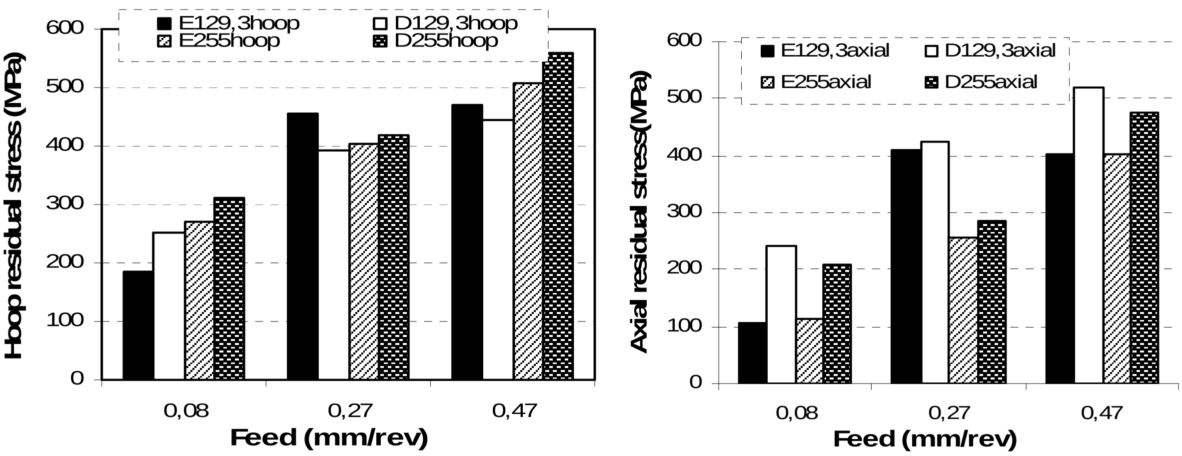
Fig. 5. Influence of cooling and lubrication and cutting parameters on surface: roughness R_a -a and waviness W_a -b (steel 00H17N14M2) [6]



(a) (b)

Fig. 6. Influence of cutting speed and feed rate on bearing ratio in turning with MQL: a- f= 0,17mm/rev; b- v_c= 164 mm/min (steel 00H17N14M2) [7]

The research into the influence of the cooling and lubrication mode in the cutting zone on residual stress conducted in association with the Linkoping University in Sweden has shown a considerable influence of dry cutting on residual stress in the surface layer (Fig. 7). The value of tensile stresses both in the hoop and axial direction largely depend on the employed cutting parameters. Depending on the cutting speed, the elimination of cooling and lubricating fluids led to a decrease or increase of hoop stress along with an increase of feed and an increase of axial stress [8].



(a) (b)

Fig. 7. Hoop (a) and axial (b) residual stresses in surface layer in turning dry and with emulsion (steel 45) [8]

4. Conclusions

The research has shown that with a proper choice of cutting parameters, the values of the analyzed geometrical surface layer parameters as well as its physical properties after dry and MQL turning are comparable to those obtained in turning with a continuous supply of cutting fluids. The results emphasize a possibility of eliminating or limiting the application of cutting fluids while cutting steel 45 and 00H17N14M2.

The current state of knowledge on dry and MQL turning encourages further research on the phenomena in the cutting zone and the characteristics of the surface layer in dry and MQL turning.
This particularly refers to:

- influence of eliminating or limiting the application of CLF on thermal phenomena in the cutting process
- surface geometrical structure, including a relation between the characteristics of the technological and operational surface layer

- physical properties of the surface layer
- air pollution around the workplace
- modeling the characteristics of the surface layer, including the cutting zone cooling and lubricating conditions
- characteristics of the surface layer in other cutting processes: milling, grinding, deep drilling – performed with or without cooling and lubricating fluids

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