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Original Research Article

Research and modeling workpiece edge formation process during orthogonal cutting

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ABSTRACT

This paper presented the study of the phenomenon of the material deformation at the edge of the workpiece during the orthogonal cutting of steel C45E and two-dimensional model of this process, developed with using the Finite Element Method. Based on the user's procedure VUMAT, the Johnson–Cook's law and Ductile Damage model were applied to describe the machined material. An extensive verification of the modeled process was performed. The phenomenon of material deformation at the edge of the workpiece during the actual orthogonal cutting process was recorded using a high speed camera. The courses of the real phenomenon with the modeled one were compared. The components of the resultant cutting force were measured during orthogonal cutting for different machining parameters. The measurement results were compared with the values of the components of the resultant cutting force calculated on the basis of numerical simulation. The studies on the burr formation mechanism were performed. The contactless measurement of selected geometric features of the burr was performed. The results of measurements of the selected geometric features of burrs obtained from the experiment were compared with those compiled based on FEM simulation.

1. Introduction

Global competition enforces the improvement of the quality, efficiency and functionality of machines and equipment. The resulting products must meet strictly determined criteria. Ensuring high reliability requires an adherence to tight tolerances on dimensions and shape. It can be seen a growing importance of the shape of the workpiece edges, where burrs are formed. The importance of issue related to the formation, prevention and removal of burrs still increases. The conducted studies show their significant influence on the course of technological process, the functionality of the workpiece and the manufacturing cost [3,9].

The mechanism of burr formation during machining is an extremely complex phenomenon. Many factors affect their size and shape. The most significant are the type of machining, properties of the cutting material, geometry of the workpiece, feed rate, cutting speed, cutting depth, cutting tool geometry and the tool path [3,5,6,10,18-21].

The degree of interactions and a multitude of factors require the analysis of the burr formation process in a wide

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range. Inspection of a single parameter does not allow affect on burr shape and size effectively. It is not possible to determine the general relation between the selected factor and the size and form of the burr without reference to the machining conditions and material properties. Effect of a single parameter is dependent on the other factors. The key researches are considered those focused on the methods of prediction, prevention and minimization of the phenomenon of burrs. Limitation of burr formation requires the integration of efforts from designing the products, through the technological process planning up to the manufacture of the workpiece [3,5,6,9].

The development of techniques to reduce the negative impact of burrs depends on [10]:

- development of predictive models using expert knowledge bases,
- progress of simulation models capable of identifying the interaction and dependencies between key parameters that affect the size and shape of the burr,
- development of CAD systems with deployed applications that allow analysis of the impact of the workpiece geometry on the phenomenon of burr formation,
- development of CAM systems with implemented applications that take into account the impact of the tool path on the form of burrs,
- definition of the geometric characteristics of burrs and their classification,
- development of standardized methods of measurement and specialized measuring sensors.

The material strongly deformed at the edges of the machined workpiece significantly influences the properties of this workpiece. It can cause premature or catastrophic failure of the unit during operation. It is the reason of machining errors. It complicates or prevents automated assembly. It causes damages to the workpieces during manufacturing (for example, the surface of the workpiece during transport). It disturbs operation of electromechanical products. It is the cause of injuries among workers. The burr forming during the machining process can affect faster tool wear, or cause the necessity of their premature replacement (due to unacceptable burr height, but not cutting edge wear). In some cases, it makes the further stages of the manufacturing process impossible. Burrs require the introduction of expensive and unproductive additional operations to the process such as deburring and part cleaning [3–5,9,11].

The goal of the study was to examine the phenomenon of the material deformation at the edge of the workpiece during the orthogonal cutting of steel C45E and development of a two-dimensional model of this process, using the Finite Element Method. Based on the examination of mechanical properties of C45E steel and the obtained results, the parameters of the constitutive model of the material were matched. Using the Abaqus/Explicit software a two-dimensional model of the orthogonal cutting process was built. Based on the user's procedure VUMAT, the Johnson–Cook's law and Ductile Damage model were applied to describe the machined material. Calculations were performed using the coupled temperature–displacement analysis. An extensive verification of the modeled process was performed. The phenomenon of material deformation at the edge of the workpiece during the actual orthogonal cutting process was recorded using a high speed camera. The courses of the real phenomenon with the modeled one were compared. The components of the resultant cutting force were measured during orthogonal turning for different machining parameters. The measurement results were compared with the values of the components of the resultant cutting force calculated on the basis of numerical simulation. The studies on the burr formation mechanism were performed. These studies were based on the test orthogonal cutting of the workpiece with a specially shaped geometry that allows free formation of burr at the edge of this workpiece. The contactless measurement of selected geometric features of the burr was performed. The results of measurements of the selected geometric features of burrs obtained from the experiment were compared with those compiled based on FEM simulation.

2. Burr formation mechanism

The selected mechanism of the real burr formation phenomenon is illustrated in Fig. 1. The scheme developed by Hashimura et al. [14] contains eight stages. It takes into account two types of materials: ductile and brittle. The first five steps of the burr formation mechanism are similar to both materials. They describe the behavior of the material to crack initiation. The last three steps illustrate the differences in the way of deformation of the material and the direction of crack propagation. Hashimura included the impact of the key material properties on burr formation mechanism.

During the first two steps of the burr forming process with decreasing distance of the tool cutting edge from of the workpiece edge a visible growth of the zone of elastic deformation occurs, and then plastic one. The deformation of the exit edge of the workpiece in the range of elastic strain takes place. During the third stage you can see the beginning of the burr formation. Below the top edge of the workpiece at its exit edge the plastic zone is formed, wherein you can observe the formation of the zone of concentration of significant deformation in a next stage. The said zone has been called a negative shear zone. During the next stages, in result of further movement of the tool the material displacement is observed at the exit edge of the workpiece around the pivoting point. The negative shear zone grows and then connects with the primary shear zone. Crack initiation occurs. In the case of ductile materials the initiated crack propagation occurs in the direction of the tool movement. The moving tool separates the chip from the machined material and also highly deforms the material at the exit edge of the workpiece to form a burr. In the case of brittle materials, the crack propagation occurs in the direction of the pivoting point of the material, and not in the direction of the tool movement. As a result of the progressive fracture stimulated by the movement of the tool the separation of a portion of material from the machined surface of the workpiece occurs. At the same time some slight deformation of the material at its edge takes place. A characteristic shape of a chip arises. The burr of a break out type is being formed. We observe decrement of material (8-II).