Metal cutting, or simply machining, is one of the oldest processes for shaping components in the manufacturing industry. It is widely quoted that 15% of the value of all mechanical components manufactured worldwide is derived from machining operations. The most influential model for metal cutting is the single-shear plane model (SSPM) of chip formation. The common notion is that new surfaces are formed simply by ‘plastic flow around the tool tip’ so that metal cutting is one of the deforming processes. A number of cutting theories and the finite element method (FEM) models have been developed based on this concept. Metal cutting simulation models are available in commercial FEM packages. However, these models predictions and numerical simulations do not agree with the trends and phenomena observed in metal cutting experiments. Therefore, it is of the utmost importance to have a physically sound model of metal cutting.

This thesis is based on a new concept that metal cutting is the purposeful fracture of the work material. To reduce the energy required for fracture, one should minimize the energy of plastic deformation of the work material in its transformation into the chip because this energy constitutes up to 80% of the total energy required by the cutting system. Increased tool life and machining efficiency are the outcomes of such an optimization. To investigate this concept requires a work material model which considers the entire process from plastic deformation, damage initiation to final fracture.

In this thesis, a work material model was developments based on the recent advancement in ductile fracture of metals. The model parameters must be determined under conditions that are pertinent to metal cutting. In machining, the work material experiences a complex, evolving multi-axial stress history. The existing testing specimens such as the notched bars and flat grooved specimens do not cover the stress triaxiality range found in machining. To generate material parameters needed in the model, a novel double-notched specimen is developed. This new specimen can cover a wide range of stress triaxiality from -0.25 to 0.6. For steel AISI1045, the plastic strain at damage initiation decreased from 0.81 to 0.17 in this range.

The developed model was implemented in FEM package ABAQUS as a user material model and used in the investigation of orthogonal metal cutting. A number of practical machining cases were investigated, including the effect of the cutting tool rake angle, cutting feed, tool-chip interface friction, and chip breaking tool features. The model predictions for these cases agreed with the trends known in metal cutting. This is a significant improvement from the published works where the model predictions often yielded different trends from the experimental results.

Different from the common practice to report the stress, strain and temperature plots, this work examined the stress triaxiality state in the primary deformation zone. It shows that the influence of the above machining parameters on the stress triaxiality correlated to the cutting force. A parameter change that resulted in an increase in the stress triaxiality reduced the cutting force, i.e. reducing the strain energy to fracture, and vice versa. This work demonstrates that metal cutting should be considered as purposefully fracture of work material. A machining process can be optimized by minimizing the energy of plastic deformation of the work material in its transformation into the chip.