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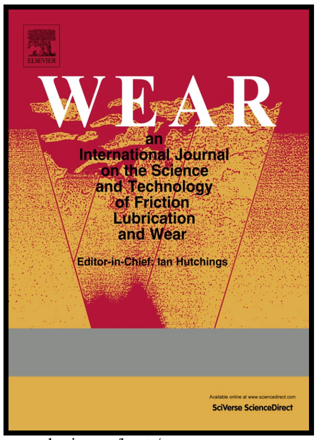

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Compilation of a thermodynamics based process signature for the formation of residual surface stresses in metal cutting

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Abstract The abrasive wear behaviour and fatigue life of many components in mechanical engineering depend on their surface stress states. Compressive surface stresses hinder ductile or brittle crack formation as well as crack propagation into the bulk material and therefore increase the lifetime of dynamically or abrasively loaded parts. The thermo-mechanical loads acting on the workpiece surface during metal cutting determine the stress state after processing. Under the high strain rates of cutting, the underlying mechanisms include the accumulation of stress fields around dislocations resulting from plastic deformation as well as thermal expansion and shrinking phenomena associated with the dissipation of mechanical energy. Until now, the underlying thermodynamics of residual stress formation in metal cutting are hardly understood quantitatively, which explains the current dominance of empirical-iterative design procedures of cutting processes regarding residual stresses.

In this work, the derivation and experimental validation of a thermodynamics based finite element model for the energy transformations during residual stress formation are presented. For the first time, the residual surface stress state is correlated with the mechanical and dissipative thermal energies, which are transformed during processing. It is shown how each residual stress component relates to these energy transformations. These findings are applied to formulate characteristic process signatures, which may be used to describe the formation of residual stresses in other manufacturing technologies as well.

The proposed work includes orthogonal cutting tests on quenched and tempered AISI 4140, subsequent determination of the residual stress states using a diffractometric measurement technique, the analytical description of the energy transformations during residual stress formation as well as its implementation into a finite element process model.

Keywords Process signature, residual stresses, metal cutting, machined surface

1 Introduction

The surface residual stress state of dynamically and/or abrasively loaded components in mechanical engineering severely influences the wear rates and the fatigue life time [1]. The stress state determines the probabilities of ductile or brittle crack formation as well as their propagation towards the bulk material. Since metal cutting is very often the last process in the manufacturing chain, its impact on the surface material modifications determines the final workpiece properties. In particular, severe shearing in the machined surface as well as severe heating and cooling, which result from dissipation and friction during cutting, may modify the residual stress state and therefore the tribological and abrasive product properties. In the automotive and aerospace industry the presence of cracks in the components' surfaces may become safety critical and therefore have to be prevented or at least have to be predictable [2]. The vast majority of available models of the residual stress development in metal cutting is empirical, which offers the advantage of efficient industrial application, whereas the validity is restricted to the studied parameters and provides only indirect evidence for physical interpretation.

Klocke attributed the formation of compressive and tensile residual stresses to thermal and mechanical effects [3]. In this respect tensile stresses result from plastic deformation following thermal expansion. After cooling down and shrinking, a tensile residual stress remains. Compressive stresses develop as a result of deformation during loading and subsequent unloading.

Concerning the impacts of the tool and process parameters on the residual stress profiles, extensive empirical results are available in the literature [4] [5] [6] [7] [8] [9]. The experimental works generally agree that the residual stress state becomes more compressive when the mechanical contribution of the material load is increased,