ELSEVIER

Journal of Materials Processing Technology 174 (2006) 82–90

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

The influence of cutting parameters on residual stresses and surface topography during hard turning of 18MnCr5 case carburised steel

Fredrik Gunnberg *, Marcel Escursell, Michael Jacobson

Product and Production Development, Chalmers University of Technology, Gothenburg, Sweden

Received 19 March 2004; received in revised form 19 March 2004; accepted 14 February 2005

Abstract

The purpose of this paper was to obtain a comprehensive understanding of the relation between cutting data and surface integrity, in terms of residual stresses and surface roughness, during hard turning with PCBN inserts in 18MnCr5 case carburised steel. In the study, fractionally reduced CCF test plan was used. It was found that the effect of cutting parameters on residual stress could only be predicted at 0–50 μm below the surface. The cutting geometry and data can be changed to alter the residual stress in area referred to above. The surface roughness values were mainly influenced by the feed rate and nose radius.

Keywords: Hard turning; Residual stresses; Surface roughness

1. Introduction

The possibility of machining hardened steel components by turning has generated interest within the industry. The process of hard turning has been studied extensively over the last decade [1,3–11]. Steel components often have to be machined after heat treatment in order to obtain the correct shape as well as the required surface finish. Hardened steel components are high performance parts, which are often loaded near to their physical limits. Therefore it is vital to understand how the finishing process affects the functional behaviour of the machined parts.

The finishing processes commonly used today are grinding and honing, but several benefits have been reported by substituting hard turning for grinding, e.g. higher flexibility and shortened lead-times. Tönshoff et al. [1] have described a process evaluation between hard turning and grinding; economic aspects, flexibility, ecological and quality criteria were specified and compared (Fig. 1). Obviously, hard turning is an interesting alternative to grinding operations under specific circumstances. The quality criteria consist of workpiece quality, process reliability and surface integrity. All three aspects of quality have to be considered in order to successfully implement hard turning.

Tönshoff et al. [1] and several other authors [3–11] have reported how hard turning influences the surface integrity of the machined part. Field and Kahles [2] describe surface integrity as the relationship between surface geometric values and the physical properties such as residual stress, hardness and structure of the surface layers. Surface integrity has a large impact on the performance of the component.

Liu and Mittal [3] report experimental evidence that the fatigue life of the hard turned surface is superior to that of a ground surface because of the more appropriate compressive residual stress profile. Liu and Mittal [3] also state that the residual stress profile can be controlled during turning, which would enable production of compressive residual stressed parts. This would enable the manufacturing of customised components e.g. bearings, with a prolonged fatigue life. The amount of residual stress beneficial for improving fatigue life differs with each application. Matsumoto et al. [4] reported that the hard turned product has as good a fatigue life as the ground product. Furthermore, it has been determined that the tool edge is the most important factor influencing the residual stress profile. Jacobson [5] investigated the effects of tool parameters and depth of cut on the residual stress in M50 steels. It was found that effective rake angle and tool

* Corresponding author.
E-mail address: fredrik.gunnberg@me.chalmers.se (F. Gunnberg).

0924-0136/$ – see front matter © 2006 Published by Elsevier B.V.
doi:10.1016/j.jmatprotec.2005.02.262

	Hard turning	Grinding	
economical aspects	+/-*	+/-*	processing time
	+	-	material remove rate
	O/+**	O/-**	cost of acquisition
	-	+	Tool costs
flexibility	+	-	multi-face machining
	+	-/O	profile maching
ecological aspects	+	-	power requirement
	+	-	coolant
	+	-	chip recycling
quality	?	+	work piece quality
	?	+	process reliability
	?	+	surface integrity

Legend:
+ positive valuation
O neutral
- negtive valuation
? valuation not possible

comment:
* depending on the application a ratio of 1:10 up to 10:1 is possible
** special purpose machine and or grinding center are often needed.

Fig. 1. Comparison of hard cutting and grinding (source: Cutting of hardened steel, CIRP 2000 [1]).

radius both affected the amount of residual stress generated. Jacobson et al. [6] also found a cutting speed that generated maximum compressive stress in bainite steel. The Thiele and Melkote [7] study showed that tool edge geometry is highly influential for surface residual stresses. In general, large edge hone tools generated compressive surface residual stresses in the axial and circumferential directions in longitudinal turning operations.

Brinksmeier et al. [8] reported that residual stresses act in a component independently of external force or moment. The internal forces form a system of equilibrium. If some part of the component is removed, the state of equilibrium is disturbed. During hard machining, the amount of material removed is minimal and the residual stress only has a limited depth of penetration of some hundredths of millimetres. The hard machining process generates residual stresses in the workpiece by plastic deformation or metallurgical transformations [8]. Vomacka and Walburger [9] described the genesis of residual stress as normal force applied on the work piece by the machining tool, causing plastic deformation and as a consequence raising the compressive stress on the surface layer. Friction between the tool and the workpiece results in heat development leading to residual tensile stress on the surface layer. König et al. [10] provided a similar explanation, in that the mechanical stress induced by the cutting tool causes a transformation of the residual austenite and strain hardening in the surface layer of the workpiece, which induces compressive stress. Thermal stress, i.e. residual stress, results from the temperature due to friction on the flank face.

How turning influences the generation of the residual stress level can be explained by considering the state of stress produced when the cutting tool slides across the workpiece (Figs. 2 and 3). The mechanism of mechanically generated residual stress during cutting (A) can be explained by a plastic deformation in the surface layer (1) and elastic deformation in the underlying surface layer (2) (Figs. 2 and 3 (left)). To achieve force equilibrium and geometric compatibility after the cutting processes, the elastic dilatation places the surface layer in residual compressive stress (B). The thermal residual stress mechanism is due to the heat of the cutting process, which expands the surface layer and produces compressive stress (A). The workpiece is then cooled (B) and contractions in the surface layer (1) produce tension residual stress, Fig. 3 (right). The thermal effect decreases further inside the workpiece, thus the main consequence of tension stress is on the surface. Consequently, the temperature of the cutting edge is very important for reducing tensile residual stress.

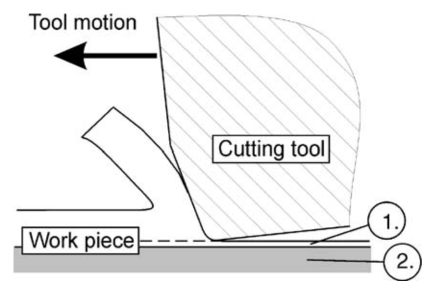

Fig. 2. Generation of residual stress by turning.

Although the way in which hard turning influences surface integrity and especially residual stress has been investigated closely, the relationship between cutting conditions and product quality must be completely understood. Therefore, to improve the quality of the machined component, a

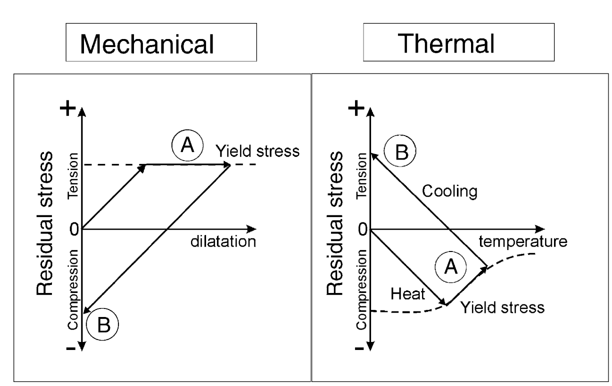

Fig. 3. The residual stress mechanism.