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Optimization of process parameter of residual stresses for hard turned surfaces

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ABSTRACT

Hard turning has been recognized as a substitute for abrasive-based processes due to its operational flexibility, economic benefit, and low environmental impact. Besides these advantages, hard turning can induce compressive residual stresses, which increase the fatigue life of the workpiece. In this paper, we investigate the process parameters of cutting speed, depth of cut, and feed rate on inducing subsurface compressive residual stress. Using a designed experiment based on a Taguchi L_9 (3^4) array, we varied process parameters over a feasible space. The resulting residual stresses were examined and evaluated by X-ray diffraction. Using the *smaller-is-better* objective function for residual stress, we then identified the optimal set of process parameters.

1. Introduction

Hard turning has been recognized as a substitute for abrasive-based processes due to its operational flexibility, economic benefit and low environmental impact (Liu and Mittal, 1995a,b). Tönshoff et al. (2000) have shown that the super-finish hard turning process enable a superior surface integrity, which is defined as surface roughness, micro hardness and residual stress. Alexandre and David (1996) have compared the surface integrity of turned and ground hardened bearing steel, and the surface integrity generated by hard turning is superior and more consistent than ground surfaces. Of the measures of surface integrity, residual stress distribution bears considerable influence on fatigue lifetimest (Webster and Ezeilo, 2001). Novovic et al. (2004) evaluated the effect of machined topography and integrity on fatigue life. Their studies make it well known that fatigue crack initiation and propagation under fatigue loading can be impeded by compressive residual stresses normal to the crack, and can be greatly accelerated by tensile residual stresses. Thus an exciting opportunity of hard turning is the capability to induce desirable compressive residual stresses. As shown by EI-Axir (2002) a method of modeling residual stress distribution, the estimation of residual stress by hard turning has become a topic of considerable scientific and technical interest in a wide variety of engineering applications. Tool flank wear has been identified as the most important factor in generating tensile residual stresses by Yang and Liu (2002), who have established a new stress-based model of friction behavior in machining and evluated its significant impact on residual stresses by finite element method. However, many extreme hard and high precision components, such as bearings, crankshafts, and gears are usually required to be machined in absence of tool flank wear. In such cases, hard turning parameters are of importance in creating advantageous residual stress distribution to enhance service capability.

Due to the inherent complexity of machining processes, the majority of the existing work on residual stress by hard turning has been limited to experimental studies (Liu et al., 2002), with few analytical models available (Michael et al., 2002). Liu and Mittal (1995a,b) have experimentally studies the superior surface integrity by single-step superfinish using hard machining. Yang and Tarng (1998) have adopted Taguchi method experimentally to optimize cutting parameters for turning operations. Fortunately, experimental results have also given a deep insight into the nature of machining processes. This paper describes finish hard turning experiments using the Taguchi method to find the set of machining parameters for residual stress distribution optimization in absence of tool flank wear.

2. Experimental procedures

2.1. Sample preparation

The samples chosen for hard turning were the inner rings of a specific type of rolling bearing. The sample heat treatment used in this study was the same as the actual rolling bearings. All the

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Table 1
Nominal chemical composition (wt%) of hardened bearing steel.

Fe	C	Cr	Mn	Si	P	S
Balanced	1.05	1.54	0.44	0.30	0.012	0.002

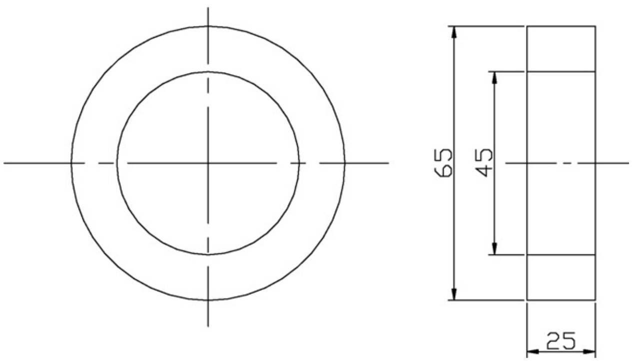

Fig. 1. The wokepiece geometrical dimensions.

hard turned samples were austenitized at a temperature of 850 °C for 2 h, quenched in oil at 70–90 °C for 30 min, then tempered at 170–190 °C for 3 h. The measured hardness for each sample was about 62–63HRC. The chemical composition of the work material as specified by the manufacturer is listed in Table 1. The geometrical dimensions of the samples are shown in Fig. 1. The face surface of the samples was super-finish hard turned using a sharp CBN insert.

2.2. Test cutting tool

The experiment adopted a cutting tool/CBN insert constructed of cubic boron nitride manufactured by Sandvik Coroman, whose $\gamma, \alpha, r_\varepsilon$ are −6°, 0 and 0.4 mm, respectively. The tool holder used for the tests was a PCLNL 1616H 09, which matches to the CBN insert as shown in Fig. 2. Before each cutting experiment, a sharp insert was installed in order to eliminate the effect of tool flank wear. A schematic diagram of the hard turning operation is shown in Fig. 3. The cutting tool was installed in an INDEX G200 numerical control machine. A 3-jaw chuck was used for chucking the samples. The rigid machine tool, hard workpiece, and sharp insert comprised a highly rigid machining system, which ensured high precision.

2.3. The hard turning experiment based on the Taguchi method

In this study, we adopt the Taguchi method, which was used by Yang and Tarng (1998), to set turning parameters for each experiment and also for data analysis. An orthogonal array was employed to investigate the entire parameter space using a small number of experiments. The measured average stress for each test run was transformed into K_{ij} and R_i. K_{ij}, Eq. (1), is the average residual stresses for a specific level, j, of turning parameter, i. In this work, K_{ij} is evaluated as *smaller-is-better* to achieve the desired compressive residual stress. The optimum level of the process parameters is that with the lowest K_{ij}. R_i, Eq. (2) reveals the order of importance of cutting speed, feed rate, and depth of cut on the residual stresses. Therefore, the optimal combination of turning parameters, and their ranking effect on residual stress can be predicted by analysis of K_{ij} and R_i.

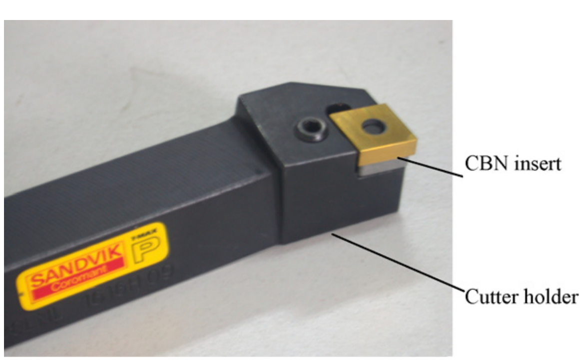

Fig. 2. Cutting tool with CBN insert.

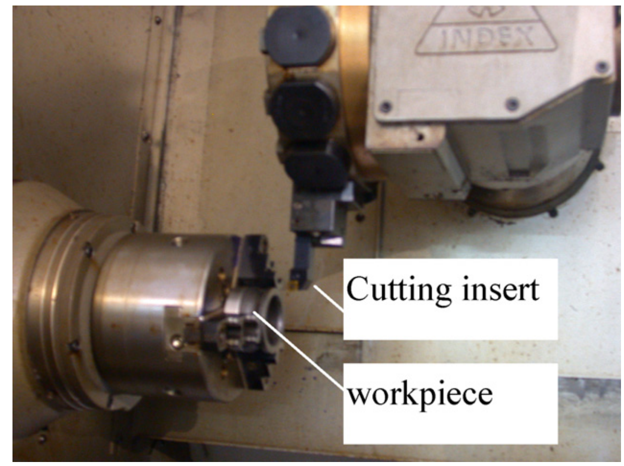

Fig. 3. Schematic diagram of facing a sample.

The feasible space for the cutting parameters was defined to be varying cutting speed in the range of 0.5–4.5 m s^{-1}, the depth of cut in the range of 0.05–0.25 mm, and the feed rate in the range of 0.025–0.135 mm rev^{-1}. A Taguchi orthogonal array, L_9 (3^4), of turning parameters was adopted in this experiment. To cover the feasible space of cutting parameters, three levels for each turning parameter were selected, Table 2. The experimental layout for these three levels of turning parameters using the L_9 (3^4) orthogonal array is shown in Table 3.

$$K_{ij} = \frac{\sum R_a(k)}{3} \tag{1}$$

$$R_i = \max(K_{i1}, K_{i2}, K_{i3}) - \min(K_{i1}, K_{i2}, K_{i3}) \tag{2}$$

where i = 1 denotes cutting speed (s), i = 2 denotes depth of cut(a_p), and i = 3 denotes feed rate (f), respectively; j = 1, 2, 3, denotes Lev-

Table 2
Cutting parameters and their levels adopted in the experiments.

Symbol	Cutting parameters	Level 1	Level 2	Level 3
s (m s^{-1})	Cutting speed	0.5	2.5	4.5
a_p (mm)	Depth of cut	0.025	0.080	0.135
f (mm rev^{-1})	Feed rate	0.05	0.15	0.25

Table 3
Experimental layout using an orthogonal array of L_9 (3^4).

Experiment no.	Cutting parameter level		
	s Cutting speed	a_p Depth of cut	f Feed rate
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1