International Journal of Fatigue 78 (2015) 46–52

Contents lists available at ScienceDirect

International Journal of Fatigue

journal homepage: www.elsevier.com/locate/ijfatigue

Influence of feed rate on surface integrity and fatigue performance of machined surfaces

Youngsik Choi *

School of Mechanical Engineering, Chung-Ang University, Seoul 156-756, South Korea

ARTICLE INFO

Article history:
Received 10 September 2014
Received in revised form 24 March 2015
Accepted 27 March 2015
Available online 11 April 2015

Keywords:
Fatigue life
Residual stress
Micro-hardness
Crack
Feed rate

ABSTRACT

This study investigates the influence of the feed rate on the surface integrity and fatigue performance of machined surfaces. The results demonstrate that a higher feed rate increases crack initiation life and crack propagation life. A higher feed rate induces more compressive residual stresses and a more softened layer. The feed rate influences crack initiation life up to 45% and crack propagation life up to 149%. Consequently, the feed rate affects fatigue life up to 132%. The fatigue tests substantiate that the feed rate influences fatigue life significantly and that the effect increases significantly if the loading is reduced.

1. Introduction

Hard machining is a single-point machining of materials with hardness above 45HRC. This process has been proposed to replace the time-consuming, abrasion-based superfinishing process. Although hard machining has many advantages over conventional methods in terms of productivity, geometric flexibility, processing cost, and surface integrity, an extensive understanding of surface integrity is demanded to implement it as a finishing process. Because the residual stress significantly influences the service performance of machined surfaces, a considerable body of research has been conducted to investigate the factors that influence the residual stress.

It was found that an increase in the depth of cut yields larger compressive residual stresses on the surface [1]. König et al. [2] demonstrated that a larger in-feed increases the level of compressive residual stresses and the depth of the affected zone. It has also been reported that hard turning induces more compressive residual stresses than grinding [3] and that the tool edge geometry is the dominant factor in determining the residual stress profile [4,5].

Li et al. [6] reported that the tool type, tool coating, tool wear, and tool breakage all influence the residual stresses of face finish turned surfaces. It was reported that a back-propagation neural network model predicts the residual stress profile of hard machined surfaces more accurately than conventional linear regression method [7]. Recently, the residual stress profile below a high-speed end-milled surface was predicted by using the Johnson–Cook plasticity model. The predictions showed a reasonable match with experimental data, although the process parameters were limited to continuous feed processes [8]. An optimal residual stress distribution was proposed to enhance the fatigue performance of hard machined surfaces by using a residual stress model [9]. It was reported that an optimal second cut can improve the state of residual stresses on hard machined surfaces [10].

Probabilistic terms have been used to predict fatigue life due to the stochastic nature of the fatigue performance of mechanical components. The size and shape of defects affect the fatigue crack initiation [11]. The presence of residual stresses should be considered in predicting fatigue crack growth and fatigue life [12]. Fatigue performance is dependent on the topology of the material microstructure, dent sharpness, and material properties [13]. It was found that the most effective ways to reduce the probability of fatigue failure are to increase the fatigue threshold and reduce the maximum crack size [14].

Hard machining produces more consistent surface integrity below machined surfaces than conventional superfinishing processes. The deterministic nature of hard machining yields more consistent repeatability of the fatigue performance, which enables more reliable prediction of fatigue life [15,16]. It was found that when compared to the maximum Hertzian stress, the maximum modified equivalent stress better predicts the fatigue life of hard machined surfaces [17]. The slope of the compressive residual stress profile was found to be an important factor in rolling contact

* Tel.: +82 2 820 5721.
E-mail address: yycc@cau.ac.kr

http://dx.doi.org/10.1016/j.ijfatigue.2015.03.028
0142-1123/

fatigue damage [18]. Guo and Barkey [19] demonstrated that the relative fatigue damage can be characterized by multi-axial fatigue damage parameters under the influence of machining-induced residual stress profiles.

Although general surface integrity factors of hard machined surfaces have been investigated, an experimental and analytical study on the influence of the feed rate on the surface integrity and fatigue performance of hard machined surfaces has not been undertaken. The machining-induced residual stress and micro-hardness distribution is a dominant factor in determining fatigue performance. Hence, this study investigates the influence of the feed rate on the residual stress and micro-hardness distribution below the hard machined surface. Subsequently, the rolling contact fatigue lives are predicted based on the residual stress and micro-hardness distribution to examine the influence of the feed rate on the fatigue performance. Rolling contact fatigue tests are then performed to verify the predictions.

2. Experimental

2.1. Specimen preparation

Specimens of through hardened AISI 1053 steel were prepared for the experiment because this steel is widely used for hard machining and bearing applications. The material properties and composition of AISI 1053 steel are listed in Table 1, and the dimensions of the specimen are shown in Fig. 1. These were selected to be uniformly through hardened and to deflect minimally due to the chucking forces of a standard jaw [20].

After the specimens were turned and ground in several steps to ensure concentricity, the flat surfaces were face turned at the machining conditions listed in Table 2. The cutting tool used in the experiment was a cubic boron nitride (CBN) tool with a tool nose radius of 0.79 mm. To investigate the influence of the feed rate, the specimens were machined at three different feed rates: 0.05, 0.15, and 0.25 mm/rev.

2.2. Residual stress measurement

The residual stress distribution was measured using X-ray diffraction. A Denver-Proto XRD 3000 residual stress analyzer with a *CrKα* radiation tube was used. The residual stress was computed by using the $\sin^2\psi$ technique [21], with nine ψ angles.

Residual stresses were measured in the circumferential and radial directions (Fig. 1) at the exposed surface and at five different depths: 5.08, 12.7, 25.4, 50.8, and 127 μm. A layer was removed by an electrolytic etcher (saturated NaCl solution) to measure residual stresses below the exposed surface. After each etching, the thickness of the specimen was measured with a Brown & Sharpe Hite-Tronic gauge to confirm the removed depth of the layer.

2.3. Micro-hardness measurement

A LECO M-400-H hardness testing machine was used to measure the micro-hardness distribution. For the subsurface measurements, the specimens were cut off and polished. The Knoop indenter was used with a 100 g load, which is the largest load that creates a clear and reliable indentation close to the surface (Fig. 2).

Table 1
Material properties and composition of AISI 1053 steel.

Elastic modulus	Poisson's ratio	Hardness	Composition (% by weight)
200 GPa	0.285	950 HK_{100}	C 0.48–0.55, Mn 0.70–1.00, P 0.04, S 0.05

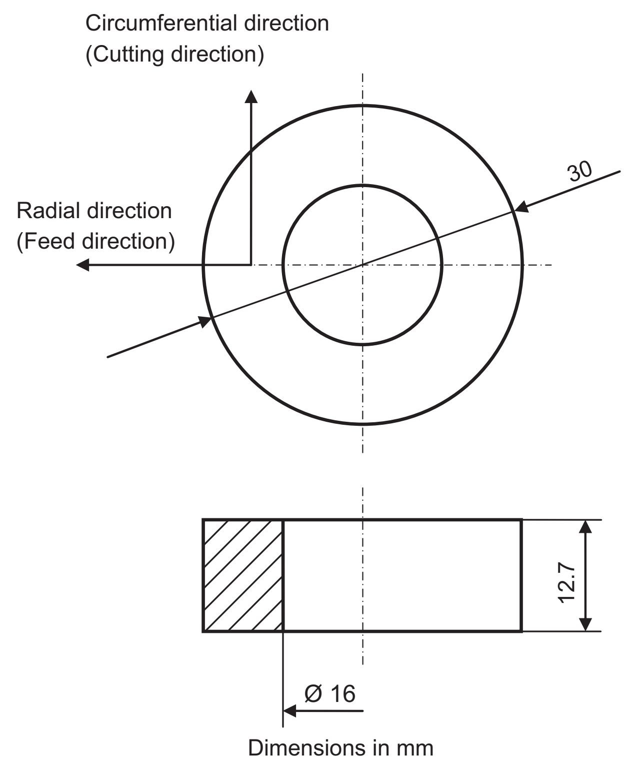

Fig. 1. Specimen dimensions.

Table 2
Machining conditions.

Parameter	Description
Cutting speed	2.0 m/s
Feed rate	0.05, 0.15, 0.25 mm/rev
Depth of cut	0.3 mm
Coolant	Dry
Rake angle	−5°

The measurements were taken at depths of 8.89, 19.05, 38.1, and 88.9 μm. These locations were chosen in the middle of the depths where residual stresses were measured. Measurement data were taken from the average of eight readings at the same depth. The indentation locations were measured using a Zeiss metallographic microscope.

2.4. Rolling contact fatigue test

Rolling contact fatigue tests were performed using a special test rig (Fig. 3), which showed less than 10–17% difference with the experimental lives measured by the Falex multi-specimen rolling fatigue tester [20]. The tests were conducted in a temperature-controlled room that was set to 25 °C. A thrust ball bearing with Grade 25 balls of 3.69 mm diameter was used for the tests.

The lower specimen was fixed in the test rig while the upper specimen was rotated at 1840 rpm. Axial loads that produced maximum Hertzian stresses of 2724, 3434, 4144, 4854, and 5564 MPa were imposed on the upper specimen. While each test was run, the specimen and bearing were immersed in SAE-30 lubrication oil, which was circulated through a 0.25 μm filtered-pump feed system at a rate of 56.8 cm^3/min.

The vibration signal was acquired by a data acquisition system during the test. To detect a spall initiation, the vibration threshold level was set to 0.2 g, which was fixed for all the tests. For each