Tribology International 80 (2014) 210–215

Contents lists available at ScienceDirect

Tribology International

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

Friction and wear behaviors of surface nanocrystalline layer prepared on medium manganese surfacing layer under oil lubrication

Dema Ba*, Fanjun Meng, Xiaoting Liu

Department of Remanufacture Engineering, Academy of Armored Force Engineering, Beijing 100072, China

ARTICLE INFO

Article history:
Received 14 May 2014
Received in revised form
2 July 2014
Accepted 9 July 2014
Available online 29 July 2014

Keywords:
Rolling
Hard
Friction
Wear

ABSTRACT

A nanocrystalline surface layer was fabricated on a medium manganese surfacing layer by rolling technology. The tribological behavior of the nanocrystalline layer was investigated under oil lubrication. The thickness of the nanocrystalline layer is 10 μm. Experimental results show that the friction coefficient and wear volume are reduced by 10% and 80%, respectively. After surface nanocrystallization, there occurs a transition from the combined action of abrasive wear and fatigue wear to the abrasive wear. The advantages realized in the tribology properties of the treated sample may be attributed to the enhancement of the hardness and the surface residual compressive stress and homogeneous oil-lubricated film.

1. Introduction

As a simple, economical and effective way to improve the wear-resisting property of the parts, the surfacing technology has currently become an important way to repair the worn parts, improve the wear-resisting properties of the parts and extend the service life of the parts, because the surfacing layer is fully dense with high cohesive strength and other advantages. It may greatly ease the energy crisis by making full use of the existing resources and saving precious metals.

Although the surfacing technology has been widely used in repair of worn parts, the following problems still exist: non-balanced coarse dendritic crystal and uneven distribution of the grain size, chemical composition and structure result in uneven surface micromechanical performance and friction and wear properties; large surface residual tension stress and poor fatigue resistance easily cause fatigue failure under alternating stress. The existence of above problems affects the application performance and service life of the surfacing parts.

With increasing evidence of unique properties for nanocrystalline materials, surface self-nanocrystallization [1–4] is expected to be a new approach to improve the fatigue resistance of conventional materials by optimizing the surface structure and refining grains [5–9]. So far, most investigations on surface nanocrystallization of metals have focused on low hardness materials. However detailed reports concerning surface nanocrystallization of surfacing layer and the corresponding friction and wear properties are rare. The conventional surface nanocrystallization device is mainly involved in Surface Mechanical Attrition Treatment (SMAT), High-Energy Shot Peening (HESP), Ultrasonic Impact, etc. SMAT is suitable only for experimental investigation, but not for industrial application. For the HEPB technology the device is complex, and the surface roughness is higher after HEPB processing. For the Ultrasonic Impact technology the processing efficiency is lower. In this paper a new surface nanocrystallization device, namely pre-load rolling technology (PLRT), is introduced. The PLRT device is similar to a regular lathe cutter, which can finish surface nanocrystallization processing of shaft parts by rolling. The surface roughness of parts is lower after pre-load rolling and hence it can be used as the last procedure of a mechanical process. Simplicity, practicality, and high efficiency are its distinguishing features.

The objective of this work is to evaluate the beneficial effects on wear resistance and contact-fatigue resistance of a nanocrystalline surface layer on medium manganese surfacing layer. A nano-structured surface layer was fabricated on the surfacing layer by pre-load rolling technology (PLRT). The microstructure of the nanocrystalline layer was characterized by different techniques and its friction and wear properties under oil lubrication were studied in comparison with the untreated surfacing sample. The reasons responsible for the improvement in the tribological properties of surface-treated samples are discussed.

2. Experimental procedure

Fig. 1 is a working schematic diagram of pre-load rolling technology, which mainly consists of the rolling head and body.

* Corresponding author. Tel.: +86 10 66718872; fax: +86 10 66718873.
E-mail address: badema0330@sina.com (D. Ba).

http://dx.doi.org/10.1016/j.triboint.2014.07.007
0301-679X/

The spring installed in the rolling body can be used to adjust the preset load. There is point-contact between the shaft part and the conical roller fixed in the rolling head during processing, and the conical roller rotates along with the shaft part; also at the same time the part surface was extruded by the conical roller under the preset load. During extruding, the surface grain of the parts is refined. During the pre-load rolling process the following parameters were chosen: the preset load was about 1800–2100 N, the feeding amount of the rolling head was 0.4 mm, the rolling frequency was 4 times, and the surface roughness before and after PLRT treatment was Ra 1.169 and Ra 0.151, respectively.

The surfacing layer is fabricated on the surface of the chrome–nickel alloy round steel. The dimension of surfacing wire is 3 mm, with the following chemical composition (wt%): C 0.2, Mn 4.2. The original structure of the surfacing layer is composed of a needle-leaved ferrite 0.2–0.5 μm in width and 2–5 μm in length and a small amount of pearlite. The hardness of the surfacing layer is HV 470. Fig. 2 shows typical TEM and SEM observations of the original surfacing layer.

A Nova nanoSEM450 model scanning electron microscope produced by FEI was used to observe the microstructure along a section perpendicular to the treated surface on the PLRTed (PLRT treated) sample. The cross-sections were mechanically polished, and etched in a 4% natal before SEM observation. The microstructure of the surface layer on the PLRTed sample was characterized by transmission electron microscopy (TEM) on a Tecnao F30 (FEI, USA) Microscope operated at 300 kV. Plane-view thin foils for TEM observations were prepared by cutting, grinding, dimpling and a final ion thinning at low temperature. An X-350A model X-Ray Stress Analyzer (ST, China) was used to measure the top surface residual stress before and after PLRT treatment.

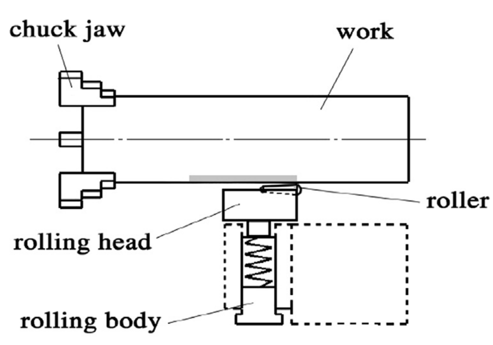

Fig. 1. Pre-load rolling technology schematic.

The hardness variation along the depth was measured along a section perpendicular to the treated surface by using a nanoindenter (CSM-NanoTest NHT-1) with a maximum load of 100 mN. The distance between any two neighboring indentations was at least 10 μm. Both loading and unloading speed were set to 100 mN/min. The hardness and the elastic modulus were evaluated using the Oliver–Pharr method based on load–displacement data obtained during the indentation tests. Each hardness and elastic modulus data was derived from the load–displacement curves of at least five indentations. The nanoindenter was calibrated by using a SiO_2 standard specimen.

The friction and wear tests were performed on a CETR-3 tester (CETR, USA) under oil lubrication condition at room temperature in air. The untreated surfacing samples were lightly polished by using abrasive papers. The roughness of untreated surfacing sample is Ra 0.182. The balls of 4 mm in diameter were made of SiC. The sample reciprocated at a frequency of 5 Hz, and the ball was fixed at the center of the samples. The test loads were 80 N, 100 N, 150 N, 200 N, 250 N and300 N, and the duration time of each test was 30 min. Under the same condition the wear tests were also performed on the untreated surfacing samples as a comparison. The wear volume loss was evaluated by using a Talysurf 5p-120 surface profile measurement instrument (with an accuracy of 0.01 μm). The morphologies of the worn surface at different wear conditions were studied by SEM. The composition of the worn surface was analyzed by using EDAX GENESIS energy dispersive spectroscopy (EDS).

3. Result and discussion

3.1. Microstructure of surface nanocrystalline layer on the surfacing layer

The cross-sectional SEM microstructures of the PLRTed sample are shown in Fig. 3. It can be seen that plastic deformations on the surfacing layer are produced by PLRT treatment. The thickness of the deformed layer is about 10 μm. The plastic deformation is inhomogeneous along the depth. On the top surface, deformation is very severe. A layer of ultra-fine structure is formed close to the top surface. There is a contrast of the super-fine structure layer on the top surface of PLRTed sample to the matrix structure, which shows that the structure of top surface is evidently fine, and it is difficult to distinguish the needle-leaved ferrite, which is outside the resolution of SEM.

Fig. 4a and b shows typical TEM plane-view observations of the top surface layer on the PLRTed sample. The microstructure is

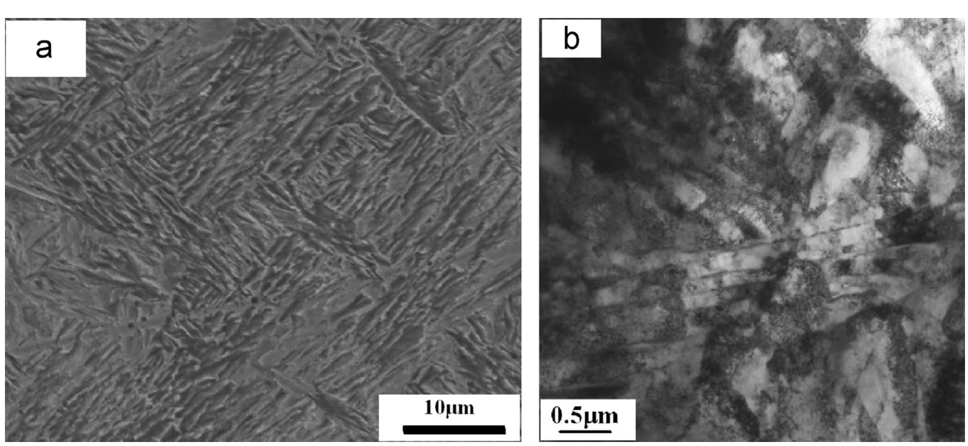

Fig. 2. SEM (a) and TEM(b) images of the original surfacing layer.