Materials Science & Engineering A 658 (2016) 77–85

Contents lists available at ScienceDirect

Materials Science & Engineering A

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

Influence of different combined severe shot peening and laser surface melting treatments on the fatigue performance of 20CrMnTi steel gear

You Lv*, Liqun Lei, Lina Sun

School of Mechanical Engineering, Jilin Agricultural Science and Technology University, Jilin 132101, PR China

ARTICLE INFO

Article history:
Received 7 December 2015
Received in revised form
16 January 2016
Accepted 18 January 2016
Available online 19 January 2016

Keywords:
Gear
Severe shot peening
Laser surface melting
Residual stresses

ABSTRACT

In this paper, the effect of severe shot peening combined with laser melting (LSMSSP for short) on the fatigue resistance of 20CrMiTi steel gears is investigated in comparison with the effect of traditional shot peening on the fatigue resistance of the laser surface melted (LSMTSP for short) 20CrMiTi steel gear. The surface characteristics of the gear have been analyzed by a scanning electron microscope (SEM) and an X-ray diffractometer (XRD). The Forschungsstelle für Zahnräder und Getriebebau (FZG) back-to-back spur gear test rig was used for fatigue experiments. Experimental results showed that the residual stresses, full width at half maximum (FWHM), microhardness and retained austenite of the LSMSSP gears and LSMTSP gear were entirely different. Although the LSMSSP gears had higher surface roughness than the LSMTSP gear, the LSMSSP gears still had better fatigue resistance than the LSMTSP gear and laser surface melted gear. The nanocrystallized surface layer on the gear tooth flank created by severe shot peening might be a very important factor for improving the fatigue property of the LSMSSP gears.

1. Introduction

A gear drive is the most important form of mechanical transmission [1]. It has many advantages, such as high transmission efficiency, compact structure, stable transmission ratio, high reliability, long durability, and so on [2]. Gear drives are widely used in many fields. Gears have become the most important part in the machinery industry. With the continuous improvements of the industrial level, increasing demands have also been raised for the strength of gears. In the transmission process, gears are subjected to a variety of forces, including bending stress, contact stress and impact force, so gears are peculiarly prone to multiple forms of failure, encompassing tooth flank pitting, spalling, wear, scoring and tooth bending fatigue [3,4]. Pitting is one of the most typical characteristics of gear contact fatigue. The main factors that affect the pitting damage are shown in Fig. 1. Pitting occurrence as less as possible will play an important role in improving the fatigue strength of gears.

For a long time, traditional shot peening (TSP for short) has been one of the most important means to improve the fatigue strength of gears in the industrial production because of its high flexibility, low production costs and little environmental pollution. In recent years, there have been many new types of peening, such as laser shock peening [5,6], ultrasonic shot peening [7,8], fine particle peening [9,10], water cavitation peening [11] and re-peening [12]. Other than those peening treatment, there is another peening treatment called "severe shot peening" (SSP for short). Comparing with TSP, SSP uses higher Almen intensities in the shot peening process. After SSP, a nano-crystalline layer has been created on the surface of the metallic material, and thus the SSPed sample has superior mechanical properties. So far, SSP has been using air blast equipment with higher Almen intensities in order to get higher kinetic energy as shown in Fig. 2, accumulating a huge mass of plastic deformation, and decreasing the grain size of the material to the level of nanometer.

Severe shot peening can also be combined with other surface treatment. S.M. Hassani-Gangaraj et al. [13,14] investigated the effect of combining nitriding and SSP on the fatigue behavior and micro-structure of ESKY-LOS6959 low-alloy steel. The experimental results show that the combination of SSP and nitriding is more effective in improving the fatigue properties of ESKY-LOS6959 low-alloy steel, compared with the single treatment. Authors [15] investigated the effect of shot peening on the fatigue resistance of laser surface melted (LSM for short) 20CrMnTi steel gear. Previous experimental results showed that the fatigue properties of the LSM+SP gears were much better than that of the laser surface melted gear. This paper studied the effect of SSP combined with laser surface melting on the fatigue resistance of 20CrMnTi steel gear, in comparison with the effect of TSP on the fatigue resistance of the laser surface melted 20CrMnTi steel gear. These research results will have important guiding significance to the future industrial production. The microhardness, residual

* Corresponding author.
E-mail address: llvvyou@163.com.cn (Y. Lv).

http://dx.doi.org/10.1016/j.msea.2016.01.050
0921-5093/

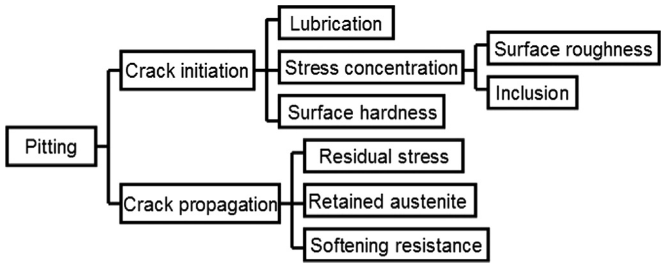

Fig. 1. The major effect factors of pitting damage.

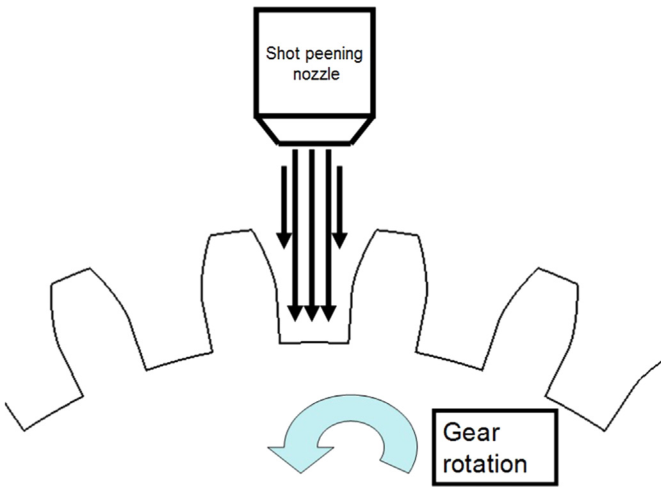

Fig. 2. A diagram of severe shot peening of gear.

stress, surface roughness, and retained austenite of LSMSSP gears would be studied under various initial surface states.

2. Experiment details

2.1. Gear material and LSM treatment

The chemical composition of 20CrMnTi steel is listed in Table 1. The laser surface melted treatment was carried out using a 4.5 kW Nd:YAG pulsed laser with a wavelength of 1064 nm, laser energy densities of 19 MJ/m^2, 25 MJ/m^2 and 31 MJ/m^2, a laser beam diameter of 1 mm, a frequency of 8 Hz, a laser scanning speed of 2 mm s^{-1}, a duration time of 20 ms and argon flowing at 20 l min^{-1} used as shielding gas. The laser-melted processing was executed by a computer numerical control program. The overlapping ratio of the successive melted tracks was 50%. The designations of the LSM gears were presented in Table 2.

The as-cast 20CrMnTi steel was composed of a coarse pearlitic-ferritic matrix, as shown in Fig. 3(a). The LSM layer in the gear tooth was free of cracks and pores. From the top of the surface, the

Table 1
Chemical composition of 20CrMnTi steel.

Element	Composition (Wt%)
C	0.17–0.23
Si	1.00–1.30
Cr	0.17–0.37
Mn	0.80–1.10
Ti	0.04–0.10%
S	$\leq$0.035
P	$\leq$0.035
Cu	$\leq$0.025
Fe	Balance

Table 2
Laser parameters for laser surface-melted 20CrMnTi steel gear.

Samples no.	Energy density (MJ/m^2)	Pulse duration (ms)	Scanning speed (mm/s)	Frequency (Hz)
LSM-1	19	20	2	8
LSM-2	25			
LSM-3	31			

LSM tooth consisted of the melted zone (MZ), the heat-affected zone (HAZ) and the substrate. The microstructure of the MZ of the LSM teeth processed under different conditions was shown in Fig. 3(b)–(d). In the MZ, the maximum temperature exceeded Ac_3 owing to the direct radiation of laser beam, and the components are uniformly distributed. Carbon and alloying elements fully diffused at high temperature to form a homogeneous austenite structure. In the subsequent process of rapid cooling, the carbon-poor needle-like martensite and a small amount of retained austenite were formed along the direction of maximum temperature gradient as shown in Fig. 3(b)–(d). With the increasing of laser energy density, the needle-like martensitic structure of the LSM gear was much more refined, especially compared with the as-cast one. The XRD pattern of the LSM-3 gear was shown in Fig. 8. All of the LSM gears were composed of phases: ferrite (α), martensite, carbide and retained austenite (γ).

2.2. Shot peening

The shot peening treatment was completed by a pneumatic numerical control air blast shot peening machine. The angle of shot peening was set through a four-axis robotic arm. The direction of shot peening was manipulated by a four-axis automatic control system to ensure that the best result of shot peening would be obtained for gears. The LSM gears were treated by shot peening with different Almen intensities. Table 3 shows the shot peening parameters for gears in detail. The shot diameter was 0.58 mm. The peening intensities for the LSMSSP gears increased from A34-36 to C6-8 Almen intensities. With an increase in the Almen intensity, the plastic deformation rate of the LSMSSP gears also increased. For comparison, the LSM gear was treated by traditional shot peening parameters, called “LSMTSP gear”. When the LSM-1 gear was treated by SSP-1 treatment, the gear was called “LSM-1-SSP-1 gear”.

2.3. Surface roughness measurement

The roughness of the gears was measured by Veeco Wyko NT1100 optical profiler 5 times each, and the surface roughness parameters could be obtained.

2.4. Residual stress measurement

The residual stresses were measured by XRD on the (211) interference line of the LSM gear tooth flank using Cr Kα radiation. The measured interference peaks were evaluated by the $\sin 2\psi$ method and the angle of ψ varied every 10° in the range of $-70°$ to $+70°$. The depth profiles of the residual stresses were determined by iterative electrolytic removal of thin surface layers and subsequent X-ray measurements.

2.5. Microhardness measurement

Microhardness along the depth of the cross-section of gear teeth was measured by a Vickers hardness tester by applying 500 g load with the dwell time of 15 s. Microhardness was the average