THE MICROSTRUCTURE AND THE FATIGUE PROPERTIES OF SHOT-PEENED CARBURIZED GEAR STEEL 20CrMnTi

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Abstract

Samples of carburized steel 20CrMnTi a,b,c,d,e and f, were differently shot-peened, then studied by x-ray diffraction, mechanical and physical measurement. The obtained macroscopic and microscopic parameters are listed in Table 1.We suggested that the summation of macrostress σ_{mac} , microstress σ_{mic} and fragmentation work density σ_w, caused by shot-peening, would be determinative for fatigue properties.

Key words : shot-peening; fatigue damage; x-ray diffraction; macrostress; microstructure.

1 Introduction

The fatigue strength can be raised 28% to 40% by proper shot-peening (1). But, the depth and the coverage of shot-peening must be controled moderately. The shot-peening can not overdid (2). If we wish to have expected materials we should keep them in optimum stress state and minimum fatigue damage (3). Generally speaking, the mechanisms of improvementing strength/toughness by shot-peening is rather complicated (4). We think that it can be considered from five different items, they are in terms of (a) macrostress σ_{mac} on large area, (b) microstress σ_{mic}, caused by work hardening, (c) work density σ_w of grainfragmentating caused by plastic deformation, (d) martenstite transformation caused by stress-inducementing and (e) properties of fatigue sources caused to stress concentration, Because nucleation, growth and propagation of cracks strongly depend on the five factors mentioned above (5). The resultant stress and its distribution are the most important factors (6).

Based on the considerations of theory and experiments (7,8,9), we suggest that the flow stress σ_p in plastically deformed metallic materials should be a resultant stress

$$\sigma_p = \sigma_o + \sigma_{mac} + \sigma_{mic} + \sigma_w + \sigma_{sp}$$

where petch stress $\sigma_o = \sigma_f + K_1 d^{-\frac{1}{2}}$ (10), $\sigma_{mac} = K_2 \frac{\lambda(2\theta)}{\lambda(\sin^2\psi)}$ (11), $\sigma_{mic} = K_3 \langle \frac{E}{V} \rangle$ (12,13), $\sigma_w = K_4 D_{eff}^{-1}$ (9), strengthening stress $\sigma_{sp} = K_5 (L-X)^{-1}$ (14) caused by second phase particles, $\langle \frac{E}{V} \rangle$ is the stored elastical energy density, i.e. average microstress level, D_{eff} is the average effective subgrain size, L is the distance between particles and X is the size of its, K_1 to K_5 are constants to be determined through experiments.

In this paper we attempt to analyse the mechanisms for improving fatigue properties and causing fatigue damages on the basis of the comprehensive analysis of the resultant stress ($\sigma_{mac} + \sigma_{mic} + \sigma_w$)

2 Experimental methods and results

The content of our samples is (%) :C 0.21, S 0.017, P 0.02, Mn 1.0 , Si 0.26, Cr 1.19, Ti 0.08, Cu o.05, Fe remainder. After carburized, we have six sets of specimens with different shot-peening, they are indicate as a,b,c,d,e and f. The tests of crooking impulse and winding fatigue were carried out on a test machine of PW 35/15 (Germany) and a PLG-100A high frequency fatigue tester (China), respectively. These deformed specimens are studied by means of peak shift and profile analysis of x-ray diffraction lines, respectively. All results were tabulated in Table 1. Where the symbols are as follows :

f_A:intensity of shot-peening ,i.e. depth of shot-peening; c_S : coverage of shot-peening; H_V: surface vickers hardness; w: impulse work; t_F: relative life time at fatigue load P_{max}=40000 ×N; σ_F: fatigue limit; σ_{macs}: internal macroscopic stress at surface; σ_{macm}=internal macroscopic stress at maximum; ρ : dislocation density; M: distribution parameter of dislocations inside domains; $\langle \frac{E}{V} \rangle$: deformation stored energy density; K_3: factor of microscopic stress concentration; σ_{mic}: maximum microscopic stress; D_{eff}: effective subgrain size,i.e.apparent domain size; K_4: parameter of domain boundary strength; σ_W: work density of fragmentation; $\sigma_{mic} + \sigma_W$: total effects of work hardening; L: subgrain size obtained by approximate function; e: microstrain obtained by approximate function; S: residual austenite content at surface; U: its highest content in some layer under surface; l: location of fatigue crack sources .

3 Analysis and summing for results

From the viewpoint of flow stress equations mentioned above, during shot-peening,the plastic deformation causes work-hardening so that the resultant stress of σ_{mac}, σ_{mic} and σ_W determines the fatigue properties. Hence samples a,b and c are less-shot-peened, f is over-shot-peened, e is optimum and d is

close by e. This is in consistence with the current idea, i.e. the effect of shot-peening is not only determined by the residual macroscopic compressive stress, but also affected by microscopic structure (5,6). The sample e has the optimum fatigue properties and its fatigue crack sources have been moved from surface layer (SL) to the next under surface layer (NSL). This is a result of shot-peening. So that (1) The macroscopic compress stress have been introduced in (SL) or (NSL) (-356or -913 N/ mm^2 for sample e). The tensile stress level with alternate loading will be drop down and the rate of crack propagation will be decreased. Thereby, the life time of fatigue has been raised and fatigue properties has been improved. (2) The defect structure in (SL) and (NSL) have been changed greatly. For example, the size of subgrain reduces evidently and the dislocation density inside subgrain increases apparently. Thereby, both the σ_{mic} and the σ_w increases greatly (σ_{mic} =167 N/ mm^2 ,it is the largest for sample e). (3) The martensite transformation induced by stress decreases the residual austenite content and increases hardness (H_V =652x10 M P_a for semple e).

Table 1 Results for shot-peened steel 20 CrMnTi

Symbol	c	a	b	e	d	f
f_A (mm)	0	0.38	0.43	0.53	0.56	0.75
cs (%)	0	200	400	200	400	large
H_V (10M P_a)	625	635	-	652	660	682
W (J)	41.3	44.0	-	34.5	34.5	-
t_F (%)	100	160	-	557	554	-
σ_F (N/ mm^2)	789	-	-	891	-	-
σ_{macs} (N/ mm^2)	+160	-282	-323	-356	-412	-
σ_{macm} (N/ mm^2)	-113	-489	-666	-913	-951	-
ρ (10^{10}/ cm^2)	7.4	12.8	-	14.0	12.5	5.4
M	2.4	12.5	-	15.6	4.5	4.5
$\langle \frac{E}{V} \rangle$ (N / mm^2)	7.0	9.8	-	16.7	12.5	10.1
K_3	10	10	-	10	10	10
σ_{mic} (N/ mm^2)	70	98	-	167	125	101
D_{eff} (A°)	710	646	-	439	177	153
K_4 (N/ mm)	0.01	0.01	-	0.01	0.01	0.01
σ_w (N/ mm^2)	141	155	-	205	565	654
$\sigma_{mic} + \sigma_w$(N/ mm^2)	211	253	-	372	690	755
L (A°)	738	249	233	163	166	-
e (10^{-3})	1.70	2.00	2.00	2.20	2.30	-
S (%)	10.56	8.10	-	5.40	-	-
U (%)	32.00	23.00	-	20.78	-	-
l (layer)	SL	SL+NSL	-	NSL	-	-

Thus we can conclude that : the process of nucleation and growth of fatigue cracks are controled by the resultant macro- and micro-stress. The fatigue life-span is determined by the properties of stress concentration source, i.e. fatigue source ,at given temperature and in actuating medium. The fatigue strength limit is resolved by the strengthening effect of solute,dislocation substructure and dispersed second phase particles. In order to reduce the damage fatigue cracks formed at the initial stage of loading by rapid static load relaxation, the primitive dislocation configuration must be controled to facilitate the rearrangement of the dislocations.

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